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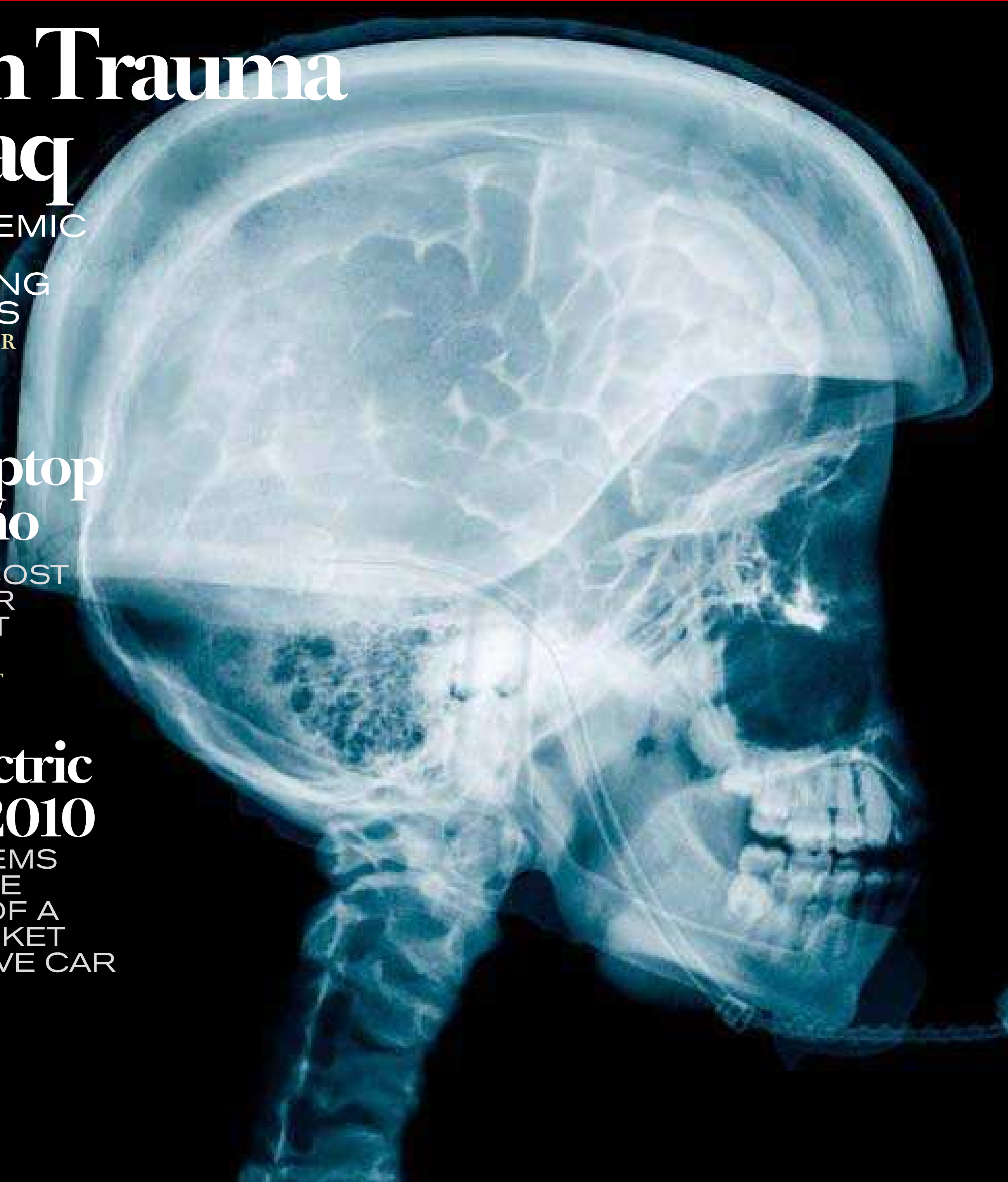

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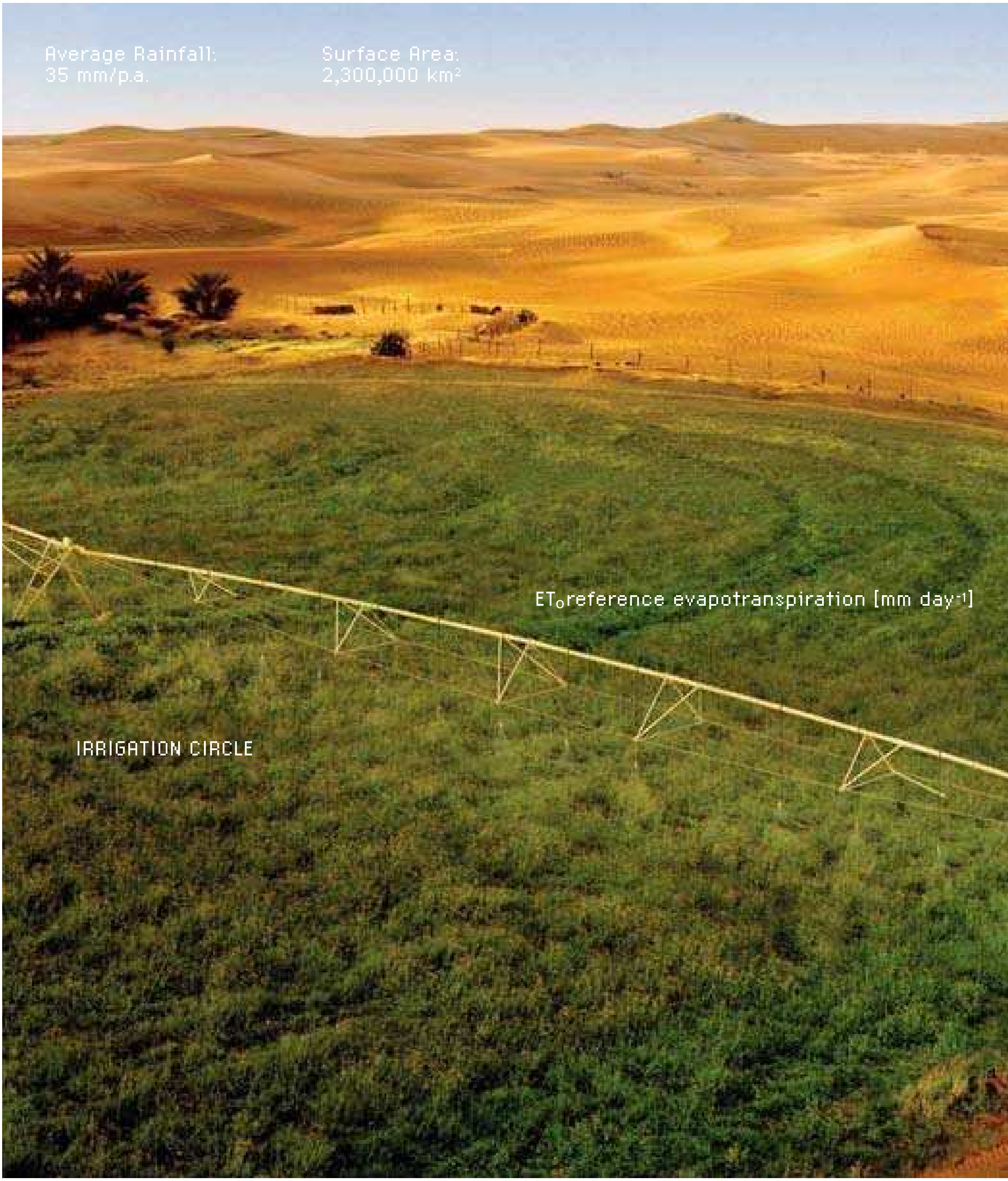

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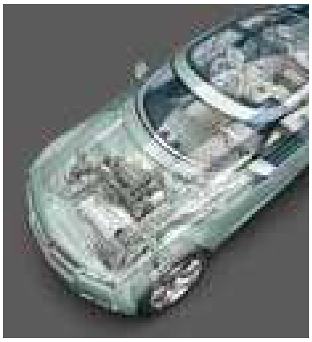

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SETH LLOYD wrote this issue's review of claims by the Canadian company D-Wave to have made a prototype of a commercial quantum computer *("Riding D-Wave," p. 78)*. "Quantum computers store and process information at the level of individual atoms," Lloyd explains. "While such devices might seem like science fiction, you can find half a dozen quantum computers scattered around the MIT campus alone. It was only a matter of time before someone tried to commercialize quantum computation, and a few years ago, D-Wave set out to do so. At first, I was bemused by their attempts, as I know how difficult it is to build a quantum computer at all, let alone to sell one for a profit. But when it became clear that they were serious, I began to follow D-Wave more closely, particularly when their quantum computer was based on a design that my graduate student Bill Kaminsky and I had proposed. I will be very interested to see whether D-Wave's device can be made to function."

Lloyd is a professor of quantum-mechanical engineering at MIT. He was the first person to develop a realizable model for quantum computation and is the director of MIT's W. M. Keck Center for Extreme Quantum Information Theory. Lloyd is also the author of *Programming the Universe*.

AMANDA SCHAFFER wrote this issue's Demo, which showcases the work of the University of Minnesota's Center for Cardiovascular Repair *("Creating a Heart," p. 88)*. The center's director, Doris Taylor, wants to use the hearts of animal cadavers as scaffolding to build new organs. Schaffer got a good look at Taylor's work. "This bioartificial heart was the most visually arresting thing I've seen in a lab in a long time," she says. "It was pink and luminous—perfectly backlit—and beating. There was also this vibe in the lab that they were onto something very cool—and they knew it."

Schaffer is a science and medical columnist for *Slate* and a frequent contributor to the *New York Times* science section. Her work has also appeared in *Bookforum*, the *Wall Street Journal*, and the *Washington Post*.

ANA CECILIA GONZALES-VIGIL photographed the students in Arahuay, Peru, featured in chief correspondent David Talbot's story on the first major implementation of the One Laptop per Child project *("Una Laptop por Niño," p. 60)*. "I was overwhelmed by how gentle and friendly the kids were," says Gonzales-Vigil. "They were holding my hand, wanting me to play with them, and kept asking me to translate the English-language books on their laptops. When I was taking pictures of children in the classroom, they did the same with their laptops, laughing and shooting pictures of *me*!"

Gonzales-Vigil's work has appeared in the *Economist*, the *New York Times, Time*, *GQ*, and many other publications.

NICK BOSTROM wrote this issue's essay on extraterrestrial life *("Where Are They?" p. 72)*, which begins by throwing a decidedly wet blanket on the quest to find life in our solar system and beyond: "I hope our Mars probes discover nothing. It would be good news if we found Mars to be sterile. Dead rocks and lifeless sands would lift my spirit." The remainder of the essay is an explanation of why Bostrom believes that the lack of life elsewhere would offer the best hope for us on Earth. Bostrom is director of the Future of Humanity Institute at the University of Oxford. Before taking that post, he was a postdoctoral research fellow in Oxford's Faculty of Philosophy, and before that, a lecturer at Yale University.

TECHNOLOGY IN IRAQ

In "A Technology Surges" (March/April 2008), David Talbot detailed the importance of the Tactical Ground Reporting System to ground forces in day-to-day operations in Iraq. DARPA has enabled rapid sharing of information and intelligence among lower-echelon forces, leading to improved effectiveness and force protection. Despite limited training in counterinsurgency, our forces have learned to use available resources to achieve desired effects, whether that is capturing insurgents, protecting themselves against IEDs, or achieving reconciliation in a given neighborhood.

However, our forces' resourcefulness should not be a substitute for learning from our experiences in Iraq at the level of the Department of Defense. That "there is a whole list of enhancements that users have requested" to this system, as Talbot reported, suggests that DOD's current intelligence processes are not necessarily a good fit for counterinsurgency operations. Better to adopt a bottom-up rather than the current top-down process designed for conventional major combat operations. Specifically, intelligence systems and architectures should be revisited to better support lower-echelon forces in a timely fashion.

Larry Lewis
Center for Naval Analyses
Suffolk, VA

THE AMAZON KINDLE

It is a little strange to see an assessment of Amazon's Kindle book reader ("What's Wrong with the Kindle," March/April 2008) by Jason Epstein, the purveyor of a rival technology, On Demand Books. It is no surprise that Epstein downplays the Kindle.

Indeed, he may well be correct that people of my age (77) are unlikely to abandon the tactile pleasures of traditional books for e-books. But that is irrelevant. My grandchildren and their cohort will surely embrace a technology that is in its infancy and can only improve with time.

Anthony Ralston
London, England

Jason Epstein, like many reviewers of the Kindle, overlooks one feature of the device that sets it apart from the competition and represents a huge advantage over physical books and the printing of such books on demand, even at a point of sale: the Kindle offers the ultimate in try-before-you-buy. You can download a book sample, usually the first chapter, in a couple of minutes, for free. The Kindle is a portable bookstore, and its freedom from the computer is genius.

Oliver Bogler
Houston, TX

THE POWER OF PLUG-IN HYBRIDS

In the Forward section of the March/April 2008 issue, you analyze the level of emissions that plug-in hybrid cars produce when they use electricity from different sources—everything from conventional coal burning to nuclear, wind, and solar power ("Plug-In Hybrids: Tailpipes vs. Smokestacks").

A major criticism of wind and solar power is that the energy produced is seldom available when it's needed. Plug-in hybrid cars might solve this problem. Commuter cars are usually stationary—either in the driveway, at work, or at the mall. As such, they can be viewed as portable energy storage devices instead of merely transportation vehicles. When the wind is blowing or the sun is shining, excess energy can be stored in the car batteries, and during peak load demand, the system can draw power from the plug-in hybrids to help system performance.

By thus utilizing nuclear and hydro power and by fluctuating between wind, solar, hybrid batteries, and combined-cycle gas-fired power plants, we could mostly eliminate the need for CO_2-intensive coal plants. And CO_2 emissions—both from electrical-power generation and from transportation fuels—could be significantly reduced.

Joseph Yarusinski
Orlando, FL

NOTES ON STAYING YOUNG

I enjoyed Jason Pontin's stimulating editor's letter on technology, creativity, and aging ("How to Stay Young," March/April 2008). In my 49 years, I've found that the key to staying creative is inductive logic. If one reads widely with an uncritical eye, processes information from unlikely sources far afield from one's area of "expertise," and manages to maintain the curiosity and awe of a child, one increases the chances of seeing patterns and identifying connections that would otherwise remain invisible. Deductive reasoning, in which truth and solutions flow only from the proven and tested, often serves as a drag on creativity.

Jerry Theodorou
West Hartford, CT

I agree wholeheartedly with Jason Pontin's notion that "we should try to be as little attached to the past as teenagers, and to satisfy our creativity not in the disparagement of new technologies but in the contemplation of how it might change our lives."

Nowhere is this more apparent than in the emerging economies of the Middle East, Africa, and India. These countries have not had the luxury of continuous technological updates, and hence neither have they had the burden of legacy systems. Fast-emerging economies such as the UAE, Qatar, and Saudi Arabia deploy the newest technologies to leapfrog over existing or absent infrastructure.

Shaheen Husain
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NOTEBOOKS

NEUROSCIENCE

Veterans in Need

CONGRESSMAN BILL PASCRELL SAYS MILITARY PERSONNEL WITH BRAIN INJURIES MUST RECEIVE BETTER CARE.

TRAUMATIC brain injury (TBI) is all too common on battlefields where blasts from improvised explosive devices pose a constant danger *(see "Brain Trauma in Iraq," p. 52)*. Today, U.S. troops do not have adequate resources for TBI prevention, diagnosis, rehabilitation, or treatment. But fortunately, things are beginning to improve.

According to an army report released in February, 11 percent of 2,994 soldiers surveyed in Iraq and Afghanistan showed signs of mild brain injury, but fewer than half of those injured were identified and evaluated in the field. The Defense and Veteran Brain Injury Center has urged that troops be screened for TBI upon discharge. As cochair of the Congressional Brain Injury Task Force, I proposed that the military prescreen all personnel before they even set foot on the battlefield and continue diagnostic analysis until the day they return to their communities. The Pentagon will soon require that troops be checked as they come home.

In 2007, Congress provided a historic $900 million to the Department of Defense and the Department of Veterans' Affairs for research and treatment of TBI and post-traumatic stress disorder. Developing the expertise to treat TBI within the DOD/VA system is a worthy goal, but so many returning TBI victims require timely treatment and rehabilitation that we need additional resources and more-immediate expertise.

For a survivor of TBI, reintegrating into the community is difficult, especially if the injury is undiagnosed or misdiagnosed. Those with brain injuries can require lifelong care, and many patients need services and help from multiple programs. Without coördinated care, they are often placed inappropriately into nursing homes or other unsuitable living situations.

One way to better coördinate care is through military-civilian partnerships. Last year, the Congressional Brain Injury Task Force worked to build a system ensuring that returning troops receive what they need to put their lives back together. The newly created Department of Defense Center of Excellence for Psychological Health and Traumatic Brain Injury, which opened its doors in November 2007, will serve as the nexus of military and civilian science and service for TBI.

The number of brain-injured troops returning from combat, added to the millions of Americans living with long-term disability as a result of TBI, convinced me long ago that publicizing, preventing, rehabilitating, and curing traumatic brain injury deserve urgent attention. My fight to expand the work of our task force, secure federal funding, and change federal policy will go on. TR

U.S. REPRESENTATIVE BILL PASCRELL JR. IS THE FOUNDER AND COCHAIRMAN OF THE CONGRESSIONAL BRAIN INJURY TASK FORCE.

PHYSICS

The New Collider

JEROME FRIEDMAN THINKS THE LARGE HADRON COLLIDER WILL SOLVE GREAT MYSTERIES.

THE RECENTLY completed Large Hadron Collider, the world's most powerful particle accelerator and most ambitious scientific instrument, is being readied to address some of the deepest questions in physics *(see "The Making of a New Collider," p. 44)*. Hundreds of feet below the surface of the earth, straddling the Swiss-French border near Geneva, it will smash counter-rotating, seven-trillion-electron-volt beams of protons against one another in a 27-kilometer ring of superconducting magnets.

With this immense energy, the LHC will be capable of producing new types of particles that are thousands of times heavier than the proton. And it will enable physicists to study phenomena at one-ten-billionth the scale of the atom. The science will be carried out with five multisystem particle detectors, the most massive of which are Atlas and CMS. Atlas is comparable in size to a seven-story building, 135 feet long and 75 feet wide; CMS, a somewhat smaller but heavier detector, weighs more than one and a half times as much as the Eiffel Tower. Each has about 100 million channels of electronic readout; with the accelerator, they constitute some of the world's most sophisticated technology.

Why is the LHC so important? The standard model of particle physics, which has been experimentally confirmed with excellent precision at existing accelerators, was a major intellectual triumph of the 20th century. But the model is not complete, because it is based on a mass-generating mechanism that has not been verified experimentally. This is the so-called Higgs field, and one of the major objectives of the

JOHN HERSEY

LHC is to confirm its existence or establish an alternative mass-generating mechanism. Theoretical calculations indicate that finding the Higgs particle, the quantum of the Higgs field, is well within reach of the LHC. Such a discovery would shed light on one of the great mysteries of nature: how mass is generated in the universe.

In this new energy range, there will be opportunities to explore physical principles and symmetries of nature that go beyond the standard model. In particular, we shall be able to search for signatures of supersymmetry, a phenomenon that has received much attention because it appears to be required in quantum theories of gravity and because it stabilizes the energy scale of the standard model against quantum fluctuations arising from processes in which particles flit in and out of existence. Supersymmetry assigns a mirror set of partners to the known fundamental particles, giving them the same electric charges but different spins. Theory suggests that the LHC is likely to be powerful enough to produce the lowest-mass supersymmetric partners. The lowest-mass uncharged supersymmetric particle is of particular interest, since it is an excellent candidate for the mysterious dark matter that makes up 23 percent of the total mass-energy of the universe.

Another question to be explored is the existence of extra spatial dimensions beyond the ones we know—a speculation prompted by string theory and by the observation that such dimensions could account for the weakness of gravity compared with the other fundamental forces. The LHC will also give rise to investigations of why the antimatter of the universe disappeared and matter remains. If this asymmetry were not embedded in our physical laws, we, and the universe as we know it, would not exist.

These and a host of other profound questions will be studied; but if history is a guide, the LHC will also turn up complete surprises, phenomena not anticipated by any theoretical speculation. The LHC will usher in a new era of discovery—findings that will stretch the imagination with the possibility of new forms of matter, new forces of nature, and new dimensions of space. It will give us a revolutionary new vision of the universe. TR

JEROME I. FRIEDMAN, INSTITUTE PROFESSOR AT MIT, WON THE NOBEL PRIZE FOR PHYSICS IN 1990.

COMPUTING

Desultory D-Wave

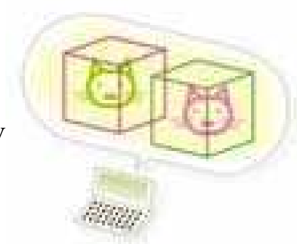
SCOTT AARONSON QUESTIONS D-WAVE'S CLAIMS OF A WORKING QUANTUM COMPUTER.

D-WAVE, a startup in Burnaby, British Columbia, claims to have demonstrated a working prototype of what it says will become the world's first "commercially viable" quantum computer. But as even its supporters admit, the company has a severe credibility problem in the scientific community *(see "Riding D-Wave," p. 78)*. In looking at its claims, I think it's helpful to ask three questions.

First, what has D-Wave actually built? Second, even if D-Wave has built a quantum computer, is there any realistic possibility of scaling it up to hundreds or thousands of quantum bits (or "qubits") in a few years—as D-Wave has repeatedly promised it will do, and as would be necessary to solve any practical problems? Finally, if D-Wave *has* built a scalable device, what problems can it solve more quickly than existing computers can?

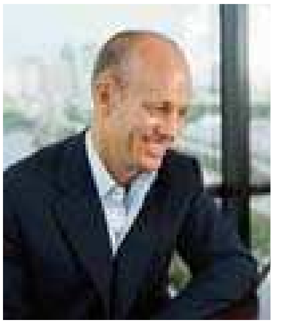
Physicists tend to doubt D-Wave's claims because it has presented no convincing evidence that its current device is quantum-mechanical. As far as any outsider knows, all D-Wave has produced is an extremely expensive and inefficient classical computer with a grand total of 28 bits. By its own admission, D-Wave has not yet demonstrated quantum "entanglement" between even two qubits. (Entanglement is a quantum form of correlation between two or more qubits; all parties agree that it is a non-negotiable requirement for quantum computing.)

Among computer scientists, another source of skepticism is that D-Wave has misled the public about what quantum computers might be able to do if we had them. In particular, D-Wave's publicity materials talk cavalierly about using its machine to solve what are known as NP-complete problems. These problems (of which the best-known example involves determining the shortest route for a traveling salesman visiting a number of cities) are important because they are common and are thought to be intractable for any computer today. However, almost all computer scientists also believe that these problems cannot be efficiently solved using a quantum computer. We have no good evidence that quantum computers—D-Wave's or anyone else's—could find even *approximate* solutions much faster than a classical computer in cases of practical interest.



Let me be clear: I think that quantum computers are possible in principle, and that D-Wave's approach might even get us there. I've also met people from D-Wave; I don't think they're frauds. But the human capacity for self-deception being what it is, scientists train themselves to look for red flags—and D-Wave is pretty much a red-flag factory. TR

SCOTT AARONSON IS AN ASSISTANT PROFESSOR IN MIT'S DEPARTMENT OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE.



MARK OSTOW

The Heroic Age

ON THE NATURAL PHILOSOPHY OF ELEMENTARY PARTICLES.

I am learning Latin—or, rather, relearning it, since I was taught the language in a haphazard way at school in England.

I set myself this whimsical task because I recalled that our masters told us that Latin made the mind supple, retentive, and acute; I am hoping that memorizing the language's endless conjugations and declensions, and submitting myself to its exacting syntax, will keep my brain plastic as I cruise into my 40s.

Yet given my daily occupations at *Technology Review*, what has struck me about Latin literature is how little the Romans thought about *philosophia naturalis*, or natural philosophy—the precursor to the modern natural sciences. They cared a little more for technology, but mainly as a branch of civil engineering, and only insofar as it was a tool of governance. Upper-class Romans exercised their intellects upon administration, law, conquest, and rhetoric. To science and technology they were indifferent.

What technologies they did possess were refinements and expansions of Greek inventions. Even their grand public buildings were different only in scale from models they appropriated from the Greek-speaking East. In science, the Romans were even more indebted to Greek civilization. The atomism articulated by the Epicurean poet Lucretius in *De Rerum Natura* ("On the Nature of Things") derives from the Greek pre-Socratic philosophers, who had speculated that the universe was composed of very small, elementary things.

Thus, in the narrow sense that they intuited the existence of elementary particles, the Greeks can be said to have invented particle physics. In "A Who's Who of the Unseen" *(p. 96)*, we reprint part of an article by the MIT physics professor Philip M. Morse, published in November 1939. He wrote, "It seems to have begun with Democritus, this idea of matter's being composed of fundamental, indivisible atoms."

But what Democritus guessed, and the Romans repeated, was unverified until recently. Morse looked forward to confirmation, through experiment, of the existence of elementary particles smaller than the parts of the atom then known to chemists: the protons and neutrons, which are part of the nuclei of atoms, and the electrons, which form a kind of penumbra around nuclei.

Thirty years later, Jerome Friedman, now Institute Professor at MIT (and a member of *Technology Review*'s board), proved that the proton and neutron were not elementary particles but were, in fact, composed of hitherto theoretical thingums, which the physicist Murray Gell-Mann had named "quarks" (after the cry of seagulls in James Joyce's *Finnegans Wake*). From 1967 to 1975, Friedman, Henry Kendall, and Richard Taylor studied the proton and neutron at Stanford University's two-mile-long Linear Accelerator by hurling electrons at tremendous speeds against a deuterium or hydrogen target. They discovered that under these extreme conditions, the proton and the neutron, rather than keeping their fundamental identity, revealed smaller particles (a phenomenon physicists call "deep inelastic scattering"). For this work, the three were awarded a Nobel Prize in 1990.

On page 10, Jerry Friedman describes a new and much more powerful particle accelerator. He explains how the Large Hadron Collider (LHC), lying hundreds of feet below the Swiss-French border, will smash seven-trillion-electron-volt beams of protons against one another in a 27-kilometer ring of superconducting magnets. Friedman calls this huge machine the world's "most ambitious scientific instrument."

A photo essay beginning on page 44 shows how the LHC works. One of the $6 billion particle accelerator's most important detectors is called Atlas: it is seven stories high and weighs more than 100 747 jets. Another, the CMS, weighs one and a half times as much as the Eiffel Tower. Scientists hope to use these detectors, and others like them, to study phenomena at a ten-billionth the scale of the atom and so complete the standard model of particle physics. In particular, they want to verify the existence of a theoretical particle called the Higgs boson, which is believed to generate mass in the universe.

Particle accelerators like the LHC and the earlier Stanford Linear Accelerator are the most beautiful machines humans have ever made, because they are incredibly complex and have no function other than to discover the fundamental nature of the universe. Scientists who use these technologies, like Jerry Friedman, are among our species' most adventurous minds.

The Roman writer and statesman Seneca wrote, "Rationale enim animal est homo": "Man is surely an animal possessing reason." True, but some humans think more deeply than others. The Romans created an oratory and poetry of unparalleled expressive power. Of their governance, the 18th-century historian Edward Gibbon wrote that "the human race was most happy and prosperous" during the interval that "elapsed from the death of Domitian to the accession of Commodus." But to the Romans the physical world was obscurely magical. Because we care to understand the world and they did not, and because of the progressive character of science, we see more clearly the nature of things. With the LHC we shall, perhaps, see the foundations of reality. The heroic age is not the classical era but our own. Write and tell me what you think at jason.pontin@technologyreview.com. *—Jason Pontin*

PHOTO COURTESY OF ACCIONA

WIND POWER IN SPAIN

SPAIN'S WIND-POWER SECTOR HAS CONTINUED ITS DRAMATIC GROWTH. INSTALLED CAPACITY IN THE COUNTRY DOUBLED IN ONLY THREE YEARS, FROM 2003 TO 2006, AND IS EXPECTED TO DOUBLE AGAIN BY 2010. SPANISH COMPANIES RANK IN THE WORLD'S TOP 10 AMONG BOTH WIND-FARM OPERATORS AND TURBINE MANUFACTURERS.

In recent years, wind power has entered the mainstream. Prices have dropped nearly to those of conventional power sources, and governments around the world are increasingly interested in renewable energy that utilizes local resources and reduces greenhouse-gas emissions. In 2007, according to the Global Wind Energy Council, more than 20,000 megawatts of capacity were installed internationally, with the United States, Spain, and China leading the way.

In Spain, where wind turbines curve over hillsides and along highways in certain areas, 2007 was a record year, with 3,523 megawatts installed—compared with an annual average of 1,200.

"It was a surprise, even for us in the wind sector," says Alberto Ceña, director of the Spanish Wind Energy Association (AEE). "We didn't expect to have this large a growth—but we are of course very happy."

The rapid expansion owed a great deal to a series of government decrees, which provided the necessary stability to encourage investment. Spanish utilities are required to purchase any wind power produced, and wind-farm operators can choose to receive a set price or sell their power on the market and receive an added premium. Though last year the United States caught up with Spain in terms of overall installed power, Spain remains third in the world.

In fact, wind supplied 10 percent of all Spanish electricity in 2007. On one record day, March 4, 2008, wind gusts sweeping the country provided 28 percent of the country's total electricity.

The Spanish government also developed strict electricity requirements, or grid codes. Because wind is an intermittent resource, providing power only when it blows, the grid has to be able to cope with fluctuations and dips in electricity. When wind accounted for only a small percentage of the country's power, such dips made little difference. But as this resource achieved greater prominence, split-second losses of power could have caused problems, especially since Spain doesn't have strong grid connections with neighboring countries.

The company Energy to Quality, created in 2005 in part by university professors in Madrid, developed a voltage-dip generator to mimic power fluctuations in a controlled fashion. The company consults with manufacturers to analyze how short circuits affect their turbines, allowing the designs to be improved.

The government specifications and company innovations make the grid interconnections in Spain among the best in the world, according to Ceña. But though wind continues to capture a greater share of electricity production, he believes there's still room for improvement. "The main challenges for the future are from the electrical point of view," he says. "We need to integrate a great deal of wind power into the system. There are many challenges, and there many Spanish companies working to find solutions."

Indeed, 500 Spanish companies now work in the wind-power sector, most providing services and equipment not only in Spain but around the world.

OPERATING THE SYSTEM

The Spanish power utility Iberdrola, which has been selling kilowatt-hours for more than a century, is the largest wind-power operator in the world, managing more than 7,700 megawatts of power in 19 countries.

"From a management point of view it's easy to have five or six wind farms, but when you have 7,700 megawatts blowing in the wind around the world, you have to also be innovative in the way you manage the assets," says Carlos Gascó, one of the directors of Iberdrola Renewables. "You have to make a huge effort in information flow on a real-time schedule."

That effort is carried out at the operations center, known as CORE. Rows of computers hum quietly in a spacious office in Toledo, south of Madrid. Huge screens along the front wall flash a variety of detailed images. Some display an international map of Iberdrola wind farms, shaded to indicate which are in operation. Others display a group of turbines at one particular facility; with the click of a mouse, an engineer can narrow in on the current, real-time operations of each turbine in every wind farm around the world.

"WE'RE TRYING TO OPTIMIZE THE MANAGEMENT SYSTEM AND THE DESIGN SO THAT THE ENERGY WE PRODUCE IS THE MOST EFFICIENT POSSIBLE."

Information flows in continuously, through fiber-optic channels and by satellite. More than a million points of data—more than 300 for each turbine—are transmitted from local and international facilities.

From this center, the company can initiate or halt machine operations as necessary. If engineers detect a problem in a turbine, they can alert local maintenance staff to investigate the problem and bring the turbine up to speed again quickly. "We want to reduce the time that any turbine is offline and allow each wind farm to produce more," says Gustavo Moreno, CORE manager.

This impressive facility was born of Spanish government regulations, which require all renewable-power operators to institute real-time control centers that send information to the Spanish grid operator, Red Electrica ("red" means grid in Spanish). The center also incorporates the company's forecasting system, which predicts the amount of wind that will be available from any given farm over the next two days.

Iberdrola has always pursued a mix of energy with a focus on clean, renewable sources, according to Gascó. Originally that meant hydropower, but in 2001 the company made a decision to invest significantly in today's cleaner technologies, including wind.

The company scaled up rapidly, from four wind farms in 2003 to more than 600 today—an expansion that demanded a rigorous approach to management. "Wind-farm operators in the past had a kind of romantic approach to energy," says Gascó. "The pioneers were engineers and technicians planting little wind farms or individual wind turbines. It has moved to being a mainstream source of power."

As Iberdrola expanded into markets around the world, Gascó says, the company also worked to navigate each country's regulations, requirements, and cultural standards. "You don't talk to someone from Argentina the same as you talk to someone in Mongolia, the U.K., or the U.S," he says.

Today, Gascó adds, Iberdrola sees wind as an important part of the energy mix. "We saw that the political impulse is today going toward something that is more sustainable—and it's the right business decision," he says. "It's also good business for a large base of shareholders. So we think that the company is very well positioned from every point of view: technically, technologically, financially, and environmentally."

Endesa, another electric company and major wind-farm operator in Spain, built some of the earliest wind farms in the Canary Islands and in the region of Catalonia and Galicia. The company has a presence in 12 countries; last year it began operating the first wind farm in Chile. It also recently signed an agreement with another of the largest developers in Spain—Enerfin, part of the Elecnor group—to jointly develop offshore wind parks in southern Spain.

"We're trying to optimize the management system and the design so that the energy we produce is the most efficient possible," says Fernando Ferrando, Endesa's director of renewable energy.

For the past two years, Endesa has sponsored a research award, open to universities, laboratories, private individuals, and businesses, for work on sustainable technologies and energy sources that minimize climate change. The four 2007 winners, from Spain, Italy, and Chile, each receive 500,000 euros (about $771,000) and access to the company's expertise in business development. One of the winners, a team including researchers from the Autono-

Engineers monitor real-time operations of wind farms in 19 countries around the world from one central location outside of Madrid.

mous University of Barcelona and the Spanish Council for Scientific Research, focused on reducing energy loss and increasing transmission capacity in the grid.

BUILDING THE MACHINES

Another large wind-farm operator within Spain is Acciona, which is also one the top 10 turbine manufacturers in the world. The company's renewable-energy portfolio includes photovoltaic and solar thermal energy, small hydraulic systems, biomass, and nearly 5,300 megawatts of wind power.

Acciona's involvement in turbine manufacturing began in 1994, when EHN (a company Acciona later bought) installed the first wind turbines in the autonomous region of Navarra, beginning with six machines near the capital city of Pamplona. Ever since, the company has worked to make its machines bigger, more efficient, and more reliable while improving their connections to the grid.

One of Acciona's most significant lines of research involves offshore wind farms, which pose distinct challenges in Spain. The offshore turbines in use or in development today stand in relatively shallow stretches of ocean. But Spain's coast drops off precipitously, and siting turbines in deep water raises technological problems that have not yet been solved.

The government recently authorized the development of wind power in selected areas off Spain's coasts and released plans to identify the most promising locations and then work with companies to develop those sites.

Researchers are designing buoys to measure meteorological information in selected areas, boats to service the machinery, and platforms to support the turbines. Platforms with a fixed foundation will work only up to a certain depth, at which point floating platforms, similar to those that support oil rigs, will be necessary. So far there are no full-scale working prototypes of floating wind turbines.

"The foundation is quite expensive—about 30 to 35 percent of the total cost of the turbine," says Carlos Itoiz, deputy executive director of renewable-technology development at Acciona. "If you mount a small machine, the cost is prohibitive. We need much larger machines to make these systems profitable."

In addition to working on the infrastructure for such systems—no small task, considering that the equipment must survive the punishing ocean environment and then transfer the power to shore—the company is developing offshore turbines with even more power, along the lines of 5 to 10 megawatts. This work necessitates still more improvements. For instance, current power cables carry energy at 132 kilovolts, but Itoiz says that larger machines and larger wind farms will require cables that can carry 220 to 400 kilovolts.

While Acciona doesn't design each part of its turbines, "we have to coördinate all of it," says Itoiz. "We work with an entire network of providers, as basically an extension of our research projects. We don't develop the cables, but we tell the companies what we need and work with them to design it." Some Spanish companies that provide those parts nationally and internationally include Ingeteam, which designs and implements the electric and electronic components of turbines, and Coiper/Comonor, which builds turbine towers. Ingeteam had supplied more than 11,000 wind power converter units as of February 2008, accounting for approximately 16 percent of the global market.

Itoiz says that Acciona plans on continuing to pioneer in this field. "Working offshore provides a number of different opportunities for research," he says. "Wind blows more steadily with less turbulence, so you might be able to use another form of wind-farm

PHOTO COURTESY OF IBERDROLA

Spanish turbine manufacturers have expanded globally, distributing to more than 25 countries in America, Europe, and Asia.

control; the speed of the rotors might be higher; you don't have to worry about noise [as developers must when onshore turbines are placed near homes]. Everything has to be more reliable, because maintenance is more challenging. You have to work on all these aspects to make offshore wind a success."

Meanwhile, Acciona is also developing a line of larger land-based turbines—three megawatts, versus 1.5 in the current line. The company has constructed the first prototype and is testing its performance.

One of the major challenges in developing larger turbines is that larger blades are brittle, and their size makes them almost prohibitively difficult to transport. One option is to create blades in sections that could be put together on the wind farm.

Another enduring challenge for wind power in general is how to capture energy during windy periods and store it for later use. The government of Galicia is exploring this question at Sotavento, an experimental wind farm it created in coöperation with a number of local and national companies. One project focuses on using wind power to split water into hydrogen and oxygen in an electrolyzer; the hydrogen can then be used in fuel cells. Acciona is involved in similar research; the company coördinates Wind-hy, a 1.5-megawatt utility-scale wind-hydrogen integration research project. Acciona plans to focus on producing hydrogen for use in fuel cells and transportation.

The largest turbine manufacturer in Spain, and the second largest in the world, remains Gamesa. The company began manufacturing turbines in 1995 and today heads a number of research and development projects in the European wind sector. One, called Reliawind, is aimed at optimizing wind systems; Gamesa is leading a coalition of 10 European partners in the venture and has invested 7.7 million euros (nearly $12 million).

"We want to develop the next generation of wind turbines," says Ricardo Elorza, a spokesperson for Gamesa. "We want to reduce the cost of maintenance and build more efficient machines. Our goal is to finish Reliawind in 2010."

Through its work with another European research project, Upwind, Gamesa is joining in efforts to develop larger turbines. The G10, an in-house prototype under development, will produce 4.5 megawatts. Researchers have been improving a control system that minimizes blade vibration and reduces blade load, making the system more efficient and better suited to use in a larger machine. Engineers are also developing a sectioned blade that can be delivered in parts and then reconstructed, thus overcoming the transportation challenge. In addition, researchers are refining a converter technology that will adapt to grid conditions in any country.

Like wind-farm operators, Spanish turbine manufacturers continue to expand their international presence. Gamesa sells turbines in more than 25 countries in North and South America, Europe, and Asia; it opened four new production centers in Pennsylvania in 2006. Acciona opened its first North American turbine production plant in Iowa in January 2008.

PHOTO COURTESY OF ACCIONA

Says Elorza, "Wind power is exceeding every expectation. You plan for a growth of 15 percent and the market grows at 30 percent. And Gamesa is growing even more quickly than the market itself, so we are in a very good position."

The engineering company MTorres, which specializes in aeronautics, has turned its sights to wind turbines as well. In an attempt to reduce the weight of larger machines, the company has developed a new model that operates without a gearbox. "This will improve the endurance of the wind turbine and ease maintenance," says Emilio Martin, sales director of the MTorres wind division. This technology is also designed to adapt to different grid codes, so the turbines could be used in different countries.

In addition, MTorres is capitalizing on its experience with composite materials, which are often used to reduce weight in planes; turbine blades made from these composites could be much lighter. Finally, the company is exploring whether a small offshore wind turbine could be coupled with a desalination plant to provide fresh water to coastal communities.

WIND BASE

The autonomous region of Navarra, home to some of the major Spanish international wind companies, is also at the forefront of renewable-energy implementation and research. The region can at times meet up to 70 percent of its inhabitants' electricity needs with renewable energy, the largest portion of it coming from wind. Wind turbines dot the low mountains that extend throughout the region, a skyline of gracefully rotating white blades.

Navarra is also home to the Center for Renewable Energy Research (CENER), which opened in 2002 to conduct research and provide testing and services for client companies. (Though it focuses on wind power, CENER also investigates biomass, solar thermal, and photovoltaic power.) Services might include testing blades to assess their field performance, or mapping wind resources and forecasting. Thirty percent of the funding comes from national and local government grants; the rest is raised from services and testing for business clients.

Says CENER director Juan Ormazabal, "We wanted to provide companies the services that they required. And sometimes we moved ahead faster than they themselves did, because if we didn't put ourselves ahead of their needs, we wouldn't be able to offer value as a research center."

In the spirit of anticipating client needs, in early 2008 CENER opened the doors to its new wind research center, the largest facility of its kind in the world. It is equipped to test the performance of machines up to eight megawatts, which are currently on the drawing board.

The massive facilities, located about 30 miles outside the Pamplona headquarters, allow researchers to test blade fatigue, gearbox functions, and grid connections. They can simulate conditions to age the machines the equivalent of 20 years in only six months. The site also includes outdoor space where companies can test full turbine assemblies.

At this facility, Gamesa and Ecotécnia partner in the project Windlider 2015, which aims to analyze blade performance and a variety of components for cutting-edge larger machines. Their goals include cutting the development time for new turbines nearly in half and reducing the energy required to produce them by 30 percent. By 2009 the companies plan to be testing 4.5-megawatt machines.

Companies don't have on-site facilities to perform this type of testing or assembly, says CENER business manager Jerónimo Camacho. "So they have to go to the wind farms, and that can cause several problems," he says. "The wind farms are very far, and they're usually not in a very friendly environment. And you need to set up many components, and you have to wait for the wind. So the tests can take a lot of time." To help address that problem,

WIND POWER IN SPAIN

Source: GWEC/AEE/IDAE/REE

Market Snapshot

- Total capacity by end of 2007 .... **15,145 MW**
- A record new capacity installed in 2007 .... **3,522 MW**
- Growth rate 2006-2007 .... **30.3%**
- Total capacity target for 2010 .... **20,155 MW**
- Contribution to national power supply in 2007 .... **9.5%**
- Peak contribution to Spanish electricity supply **28%**
- Equivalent number of households supplied **8.4M**
- Total generation at the end of 2007 .... **26,528 GWH**

Economic Growth - Employment

- Total jobs in wind industry at the end of 2007 .... **45,000**
- Total companies in wind industry in 2007 .... **500****

**Approximate

Wind supplied 9.5 percent of all Spanish electricity in 2007.

CENER is now constructing a 30-megawatt experimental wind farm in Navarra.

In addition, CENER works across five continents in emerging markets such as Costa Rica, Panama, and the Dominican Republic, helping set up regulations to facilitate investment in wind farms and then assisting in their development.

"I think that renewable energy is going to have an extremely important growth," says Ormazabal, "and emerging countries see this as the opportunity to put themselves on the same level as other countries."

FORECASTING THE FUTURE

Because wind provides power only intermittently, grid operators working to maximize efficiency need to know how much energy will be available at any given time. Under Spanish regulations, wind-farm operators sell their power to the grid and must predict how much wind they will be contributing; the operators pay penalties for inaccurate prediction. (In other national markets, operators are not penalized for these errors.)

The apparent burden this requirement places upon companies has turned into an opportunity. Spanish companies have taken the lead in microsite prediction—forecasting what will happen at a specific turbine, given the meteorological conditions. In fact, 90 percent of Spanish wind farms use prediction services from one Madrid-based company, Meteológica. The small firm has the largest market share of wind forecasting in the world.

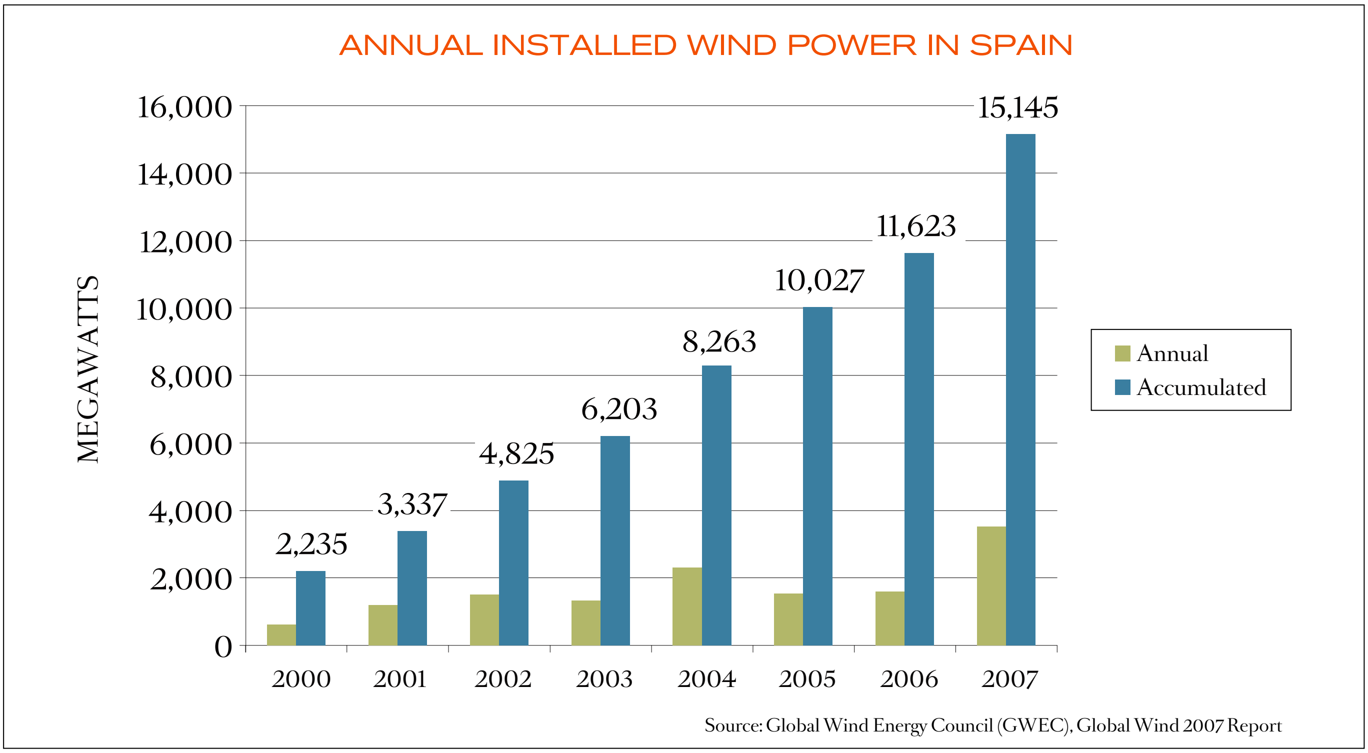
"There was a highly competitive environment, because companies needed to be able to forecast as accurately as possible," says Manuel Blanco of Meteológica. "In Spain this has made us very successful; we developed a simple system that is able to very accurately forecast the generation of wind farms."

Meteológica began operations in 1997, developing an automated forecasting system that it began marketing in 2000. Soon the company was providing services for Spanish national and local government offices that needed to predict, for example, agricultural conditions or the chance of forest fires.

"After a few years we started to develop systems to forecast variables of interest to our clients," says Blanco. The company developed models not just to predict the likelihood of forest fires but to model how those fires would evolve; not only to predict rainfall but to forecast water flows in specific rivers and, thus, hydrological power generation in the country.

Wind power was a natural business evolution. "In 2002 we developed a system that was able to forecast the output of the plant in kilowatt-hours, not just predict the wind speed," says Blanco. The company began working with four wind farms that year and now manages forecasting for more than 600, predicting outcomes for about 15,000 megawatts of power.

PHOTO COURTESY OF THE SPANISH WIND ENERGY ASSOCIATION (AEE)



The model works by taking advantage of different global atmospheric models and the meteorological information available from various satellite systems. Engineers input this information along with the conditions on the ground. They have developed statistical models that learn from the wind farm's actual performance and use that information, coupled with the input, to forecast conditions an hour to two days ahead.

"If a wind farm has been working for the last year, we know every hour how many megawatt-hours it produced," Blanco says. "So we take this on-the-ground experience and use it with the information from the global atmospheric model. And we've developed the statistical relationship, the equation, that translates these atmospheric conditions into generation in megawatts."

He admits that the model is weakest when a turbine first begins operation and works best after a wind farm has been running for a while. For the first week or two, the company makes its forecasts partly on the basis of simulations from other wind farms, but that's not necessary for long.

"It has an exponential learning curve," says Blanco. "In a few months the system has seen almost every atmospheric condition possible on that farm. And a month is nothing in the life of the wind farm"—a typical facility is usually expected to produce power for about 20 years. He says the company has probably improved the accuracy of its wind-power forecasting by about 40 percent since 2003.

Meteológica works with wind farms across Europe and in North America and Asia as well, though international expansion has been cautious and deliberate. Instead of opening marketing offices in a variety of countries, the company attracts new clients through personal meetings and the strength of its track record. All the computations are done from the 17-person office in Madrid.

Another company important in forecasting is Kintech, which provides technology and equipment for collecting meteorological information. Its sensors and data loggers have captured most of the Spanish market, and its devices measure conditions in more than 50 countries. According to general manager Tirso Vasquez, the company has succeeded by customizing remote satellite communications from the data loggers to the customers' needs.

Systems for understanding wind potential in a given region still have the capacity to get better. To that end, AWS Truewind, an American powerhouse in wind-farm siting and forecasting, joined forces with the Spanish company Meteosim, a spinoff of a meteorological research team at the University of Barcelona. Having honed its technique in small, narrowly focused areas, Meteosim began working with new models for mapping wind resources around the world, providing that information to governments, nonprofit institutions, and potential wind-farm developers.

"Typically the main approach has been to install a tower, wait

for two years, and see how much wind the wind developers or someone has been measuring on that tower," says Meteosim director Joan Aymamí. Instead, Meteosim provides mapping information on specific, narrowly defined sites. "With this approach, a client has a very accurate idea of where to go, where are the best places in a big region."

ISOLATED SYSTEMS

Spain is something of an energy island; its grid connections with neighboring France and North Africa are weak. Even more isolated are the Spanish Canary Islands, an archipelago of seven small island systems. Nevertheless, the Canary Islands have devoted local resources to investigating the best ways to move wind power into the future. They hope to serve as an example for islands and rural communities around the world.

"In the Canary Islands, the grids are weaker than in Europe, and there are islands around the world with even weaker grids," says AEE director Alberto Ceña. "The challenge is how to integrate wind with diesel engines or fuel engines. We still need to work a lot on that. The experience of the Canary Islands is going to be very useful in the future of wind power."

In fact, the islands were, along with Tarifa on Spain's southernmost border, the site of the country's first wind farms in the early 1990s. Development slowed, but the local parliament's 2006 decision to produce 25 percent of the region's electricity from renewable energy by 2015 spurred an increase in development.

The Canary Islands Institute of Technology (ITC), a regional government research center, has continued working to develop systems that look ahead to the island's future. "The Canary Islands are a real laboratory and can serve as the ideal platform for testing new energy technologies," says ITC director Gonzalo Piernavieja.

One recent project involves the island of El Hierro, which has a population of 10,500. The government recently announced a plan that would enable the island to derive 100 percent of its power from renewable sources. The key will be 10 megawatts of wind power connected to a pump system. When wind blows so fiercely that locals can't utilize all the energy, the extra power will be used to pump water up a nearby mountain to two reservoirs, one of which is a natural volcanic crater. When the wind drops, the water will fall and turn a turbine. This pumping system has been paired with other forms of electricity, but it's never been used with wind power before. In addition, the entire system will be connected to a desalination plant to provide potable water.

The dimensions of El Hierro make this small, windy, mountainous desert island the perfect laboratory for testing the new system. Installation will begin within the next year, but Piernavieja says it does offer challenges: "We have to dimension all the electrical protections and wirings, and we have to account for stability in frequency and voltage. This is not a trivial issue in this kind of renewable-energy electricity grid."

ITC is also working on a system to couple wind power with hydrogen production. A small 10-kilowatt wind-power generator connected to an electrolysis machine was inaugurated in October 2007, along with a larger 100-kilowatt system. "It's difficult—the components are not easy to manage—but we are learning," says Piernavieja. "Our main focus of research is coupling the wind energy and hydrogen production systems, because electrolyzers are not meant to work with intermittent power, and there's no book to read about integration or installation technology." There are only a handful of such integrated systems in the world.

Says Piernavieja, "We want the islands, particularly the Canary Islands, to be the first hydrogen economies, and the first regions where renewable-energy storage devices are implemented or tested—because islands are kind of showcase of what will happen in continental areas in the future. This is our vision."

And as the Canary Islands work to become a model for islands and rural areas internationally, so Spain—and Spanish companies—hope to show the world just what the wind might bring.

Resources

ICEX (Spanish Institute for Foreign Trade)
www.us.spainbusiness.com

AEE (Spanish Wind Energy Association)
www.aeeolica.org

AEH2 (Spanish Hydrogen Association)
www.aeh2.org

APPA (Association of Producers of Renewable Energies)
www.appa.es

APPICE (Spanish Fuel Cells Association)
www.appice.es

ASIF (Spanish Association of the Photovoltaics Industry)
www.asif.org (in Spanish only)

CIEMAT (Center for Research in Energy, the Environment, and Technology)
www.ciemat.es

IDAE (Institute for Energy Diversification and Savings)
www.idae.es

PSA (Almeria Solar Platform)
www.psa.es

To find out more about New Technologies in Spain, visit:
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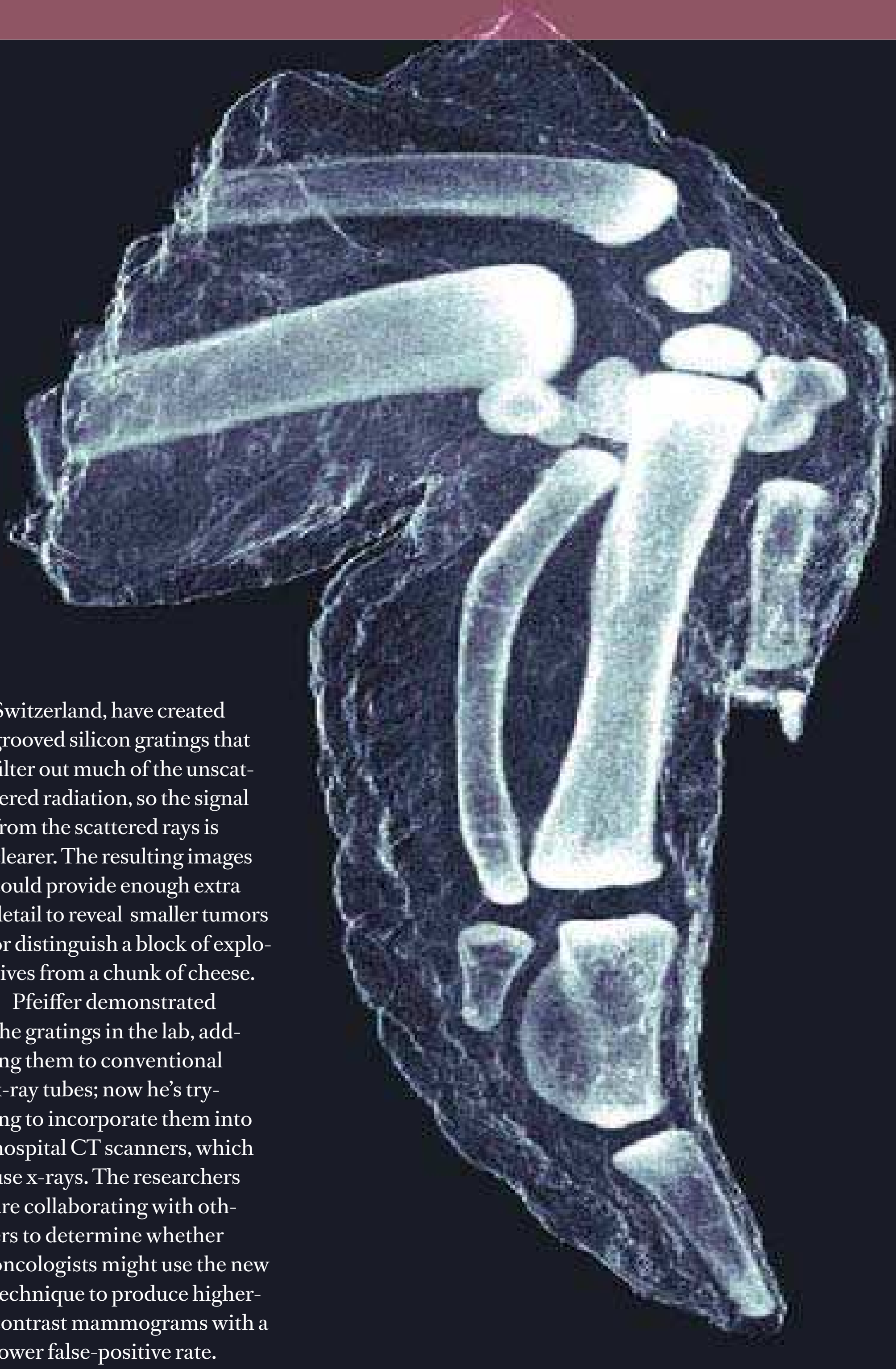

SHARPER IMAGE Details of the bone and tissue of a chicken wing are revealed by a technology that could enhance conventional x-rays. The prototype version uses more radiation than usual and isn't yet approved for human patients.

IMAGING

REMAKING X-RAYS

Silicon gratings heighten contrast

THE BASIC physics behind x-ray imaging haven't changed in more than 100 years. While most hospitals and airports have gotten rid of film and gone digital, their systems still record how much x-ray radiation passes through your arm or your suitcase and how much is absorbed. But the bones in your arm don't just absorb x-rays; they also "scatter" them, or deflect them from their paths. Those scattered x-rays could yield valuable information, but they tend to get drowned out by the stronger signal from unscattered rays. Now Franz Pfeiffer, assistant professor of physics at the École Polytechnique Fédérale de Lausanne, and Christian David at the Paul Scherrer Institut in Villigen, Switzerland, have created grooved silicon gratings that filter out much of the unscattered radiation, so the signal from the scattered rays is clearer. The resulting images could provide enough extra detail to reveal smaller tumors or distinguish a block of explosives from a chunk of cheese.

Pfeiffer demonstrated the gratings in the lab, adding them to conventional x-ray tubes; now he's trying to incorporate them into hospital CT scanners, which use x-rays. The researchers are collaborating with others to determine whether oncologists might use the new technique to produce higher-contrast mammograms with a lower false-positive rate.

—*Katherine Bourzac*

COURTESY OF FRANZ PFEIFFER (EPFL AND PSI)

SPACE

BOLDLY GOING BACK

Private effort ignites unmanned lunar race

AS EARLY as next year, Red Rover, a prototype robotic vehicle being built at Carnegie Mellon University, may be sending back stunning images and video from the moon. William Whittaker, the CMU professor whose driverless SUV triumphed on a course of urban and suburban roads in the Defense Advanced Research Projects Agency's Urban Challenge last year, is using the same technologies in the one-meter-wide moon-bot (above, at a CMU test site).

The CMU team is an early entrant in a contest funded by Google and administered by the X Prize Foundation; $20 million will go to the first privately funded team whose rover reaches the moon, travels 500 meters, and returns images and data to Earth. Whittaker has formed a company, Astrobotic Technology, and is working with Raytheon and the University of Arizona on precision landing technologies. Nine other teams are also readying entries; X Prize estimates that their efforts could cost between $15 million and $100 million each. Despite the expense—and the competition—Whittaker is confident. "We have superior software for things like position estimation, route planning, and perception to sense the terrain," he boasts. But he did not elaborate on where his team will get funding. —*Brittany Sauser*

A ROBOT'S GIANT LEAP

Red Rover's planned 2009 mission

1 A conventional two-stage solid rocket will launch a lunar lander containing Red Rover on its five-day trip to the moon.

2 The lander's computer-vision system will lock on to lunar landmarks and guide the spacecraft to a soft landing.

3 The lander will touch down near the site of the historic July 20, 1969, manned Apollo landing.

4 Red Rover will detach an antenna and point it toward Earth to enable data transmission to Earth stations.

5 Red Rover will navigate the terrain, avoiding obstacles as it follows a course plotted by controllers on Earth. If it runs into trouble, the controllers can take over, piloting it remotely.

6 To be eligible for a $20 million prize, Red Rover must travel 500 meters, stopping twice to transmit high-resolution 360° photographs, normal and high-resolution videos, and self-portraits.

7 For additional prize money, the rover may drive five kilometers, search for and take pictures of old Apollo hardware, look for ice, and attempt to survive one frigid lunar night, which lasts 14.5 Earth days.

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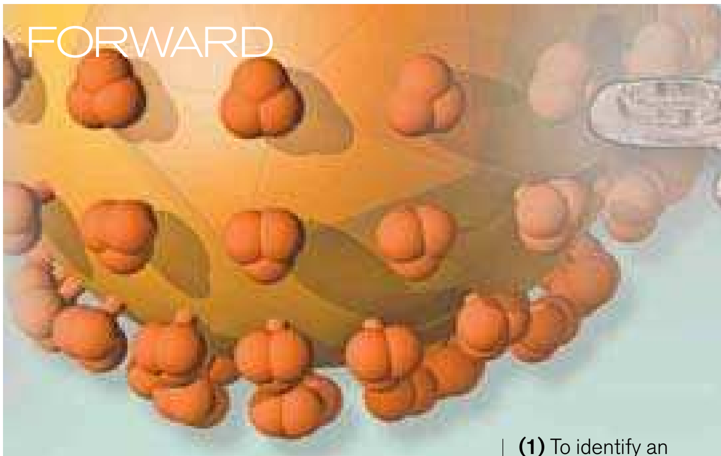


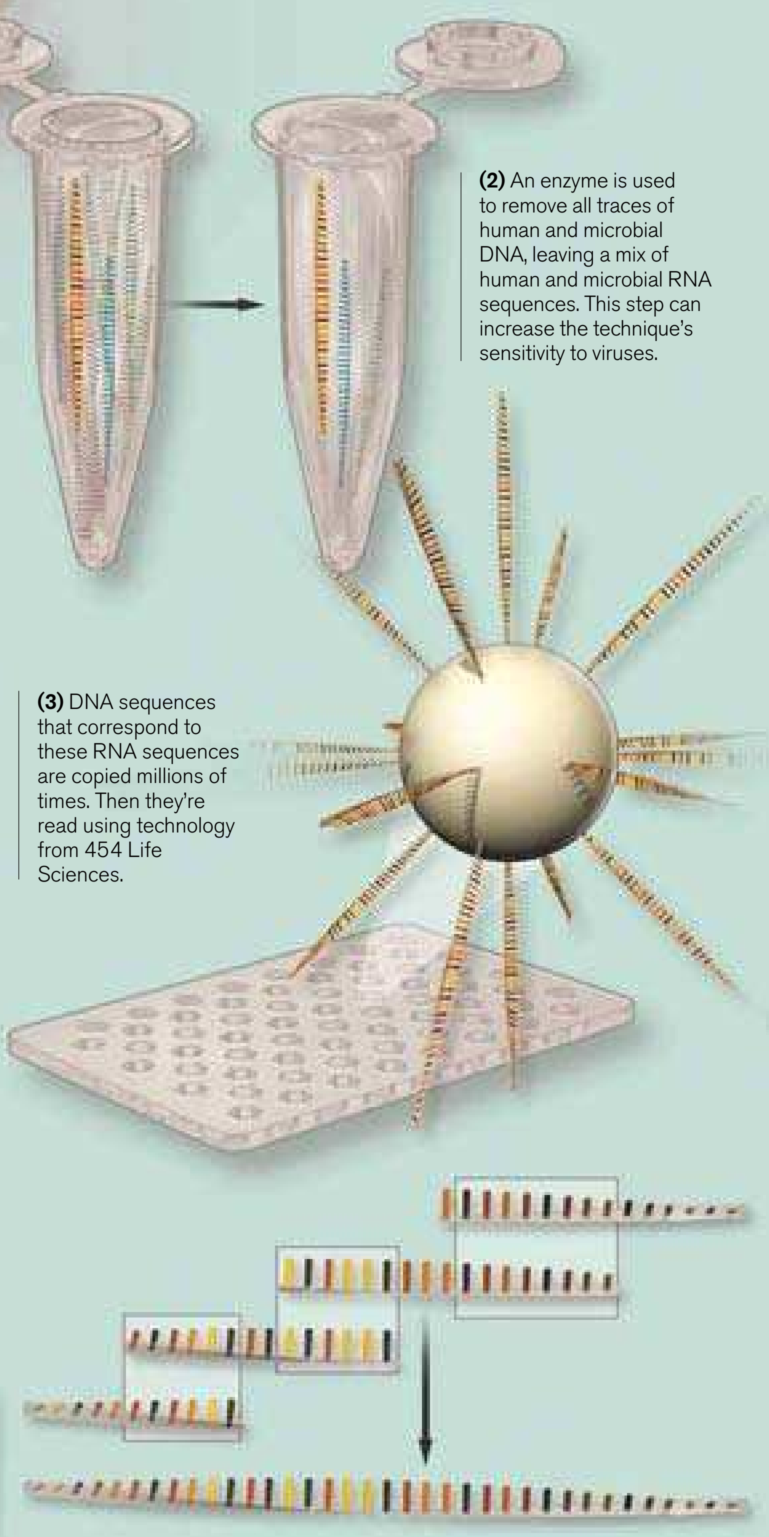
BIOTECH

CATCHING A PATHOGEN

A new process identifies mystery microbes

WHEN A particularly deadly pathogen appears, any delay in identifying it can slow the development of treatments and diagnostic tests. But until recently, identifying a pathogen usually required some advance knowledge of its genetic makeup. Now a team led by W. Ian Lipkin, director of the Center for Infection and Immunity at Columbia University's Mailman School of Public Health, has shown how to use advanced gene-sequencing technology to identify even the most mysterious pathogen. Lipkin starts by partly isolating a pathogen's genetic material from that of its human host. Then he sequences the sample using technology developed by 454 Life Sciences of Branford, CT; unlike other systems, 454's doesn't require prior information about the sequence you are looking for. Finally, Lipkin searches a database to see if any known sequences match the ones he's identified.

The team's first feat: identifying the virus that killed three Australian transplant patients who had received organs from a single donor. Lipkin has since used the technique to identify more than 20 viruses. *—Jocelyn Rice*



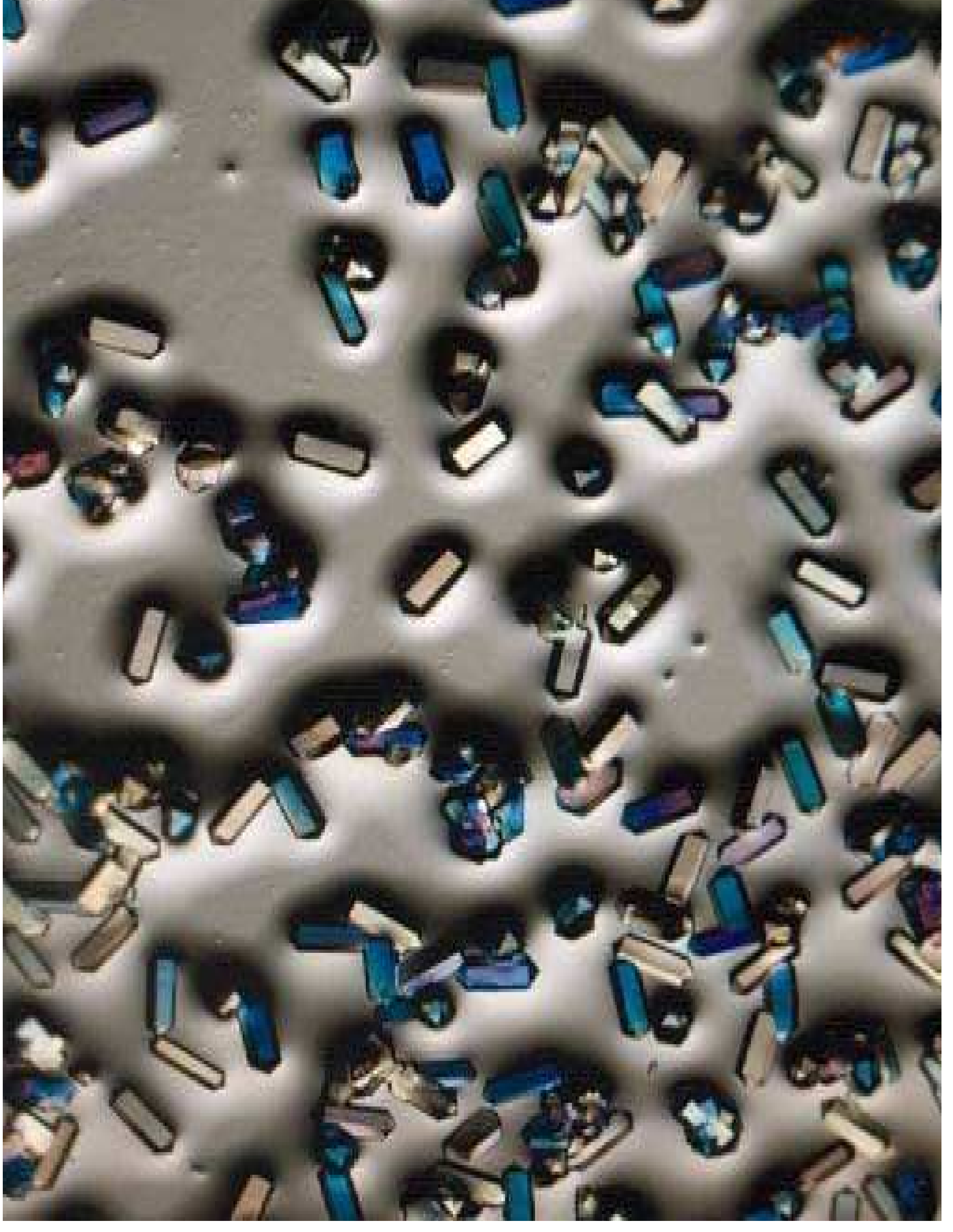
(5) Bioinformatics software compares the microbial fingerprint against databases of known microbial sequences, searching for close matches. Once the variant is fully characterized, diagnostic tools can be developed to detect the microbe in future patients.

TAMI TOLPA

MATERIALS

A CHEAP CO_2 TRAP

Crystals could capture greenhouse gases released by power plants



GAS EATERS These man-made crystals, less than one millimeter long, can capture up to 80 times their volume in carbon dioxide.

COURTESY OF YAGHI RESEARCH GROUP

IT'S POSSIBLE today to chemically capture carbon dioxide emitted by smokestacks. But the process is expensive and energy intensive, and it can inflate the cost of electricity produced from coal by 80 to 90 percent.

A new material could reduce that cost significantly. A group led by Omar Yaghi, a chemist at University of California, Los Angeles, combined organic molecules and metal atoms to form highly porous crystals whose structure resembles that of industrial materials called zeolites. A liter of the UCLA crystals stores up to 80 liters of carbon dioxide. Yaghi's materials, which can be custom-made with different pore sizes and internal structures, have an electrostatic attraction to carbon dioxide, selectively trapping molecules of the gas inside their pores. The carbon dioxide can be released by a mere drop in pressure. Then it could be compressed and stored underground indefinitely, never entering the atmosphere.

Yaghi is continuing to develop versions of the material that could offer even better performance. The power industry will need to get involved to see what savings will result at real power plants, he says. But he adds that it should be possible within two to three years to test the materials under actual operating conditions. *—Kevin Bullis*

CAPTURING CARBON

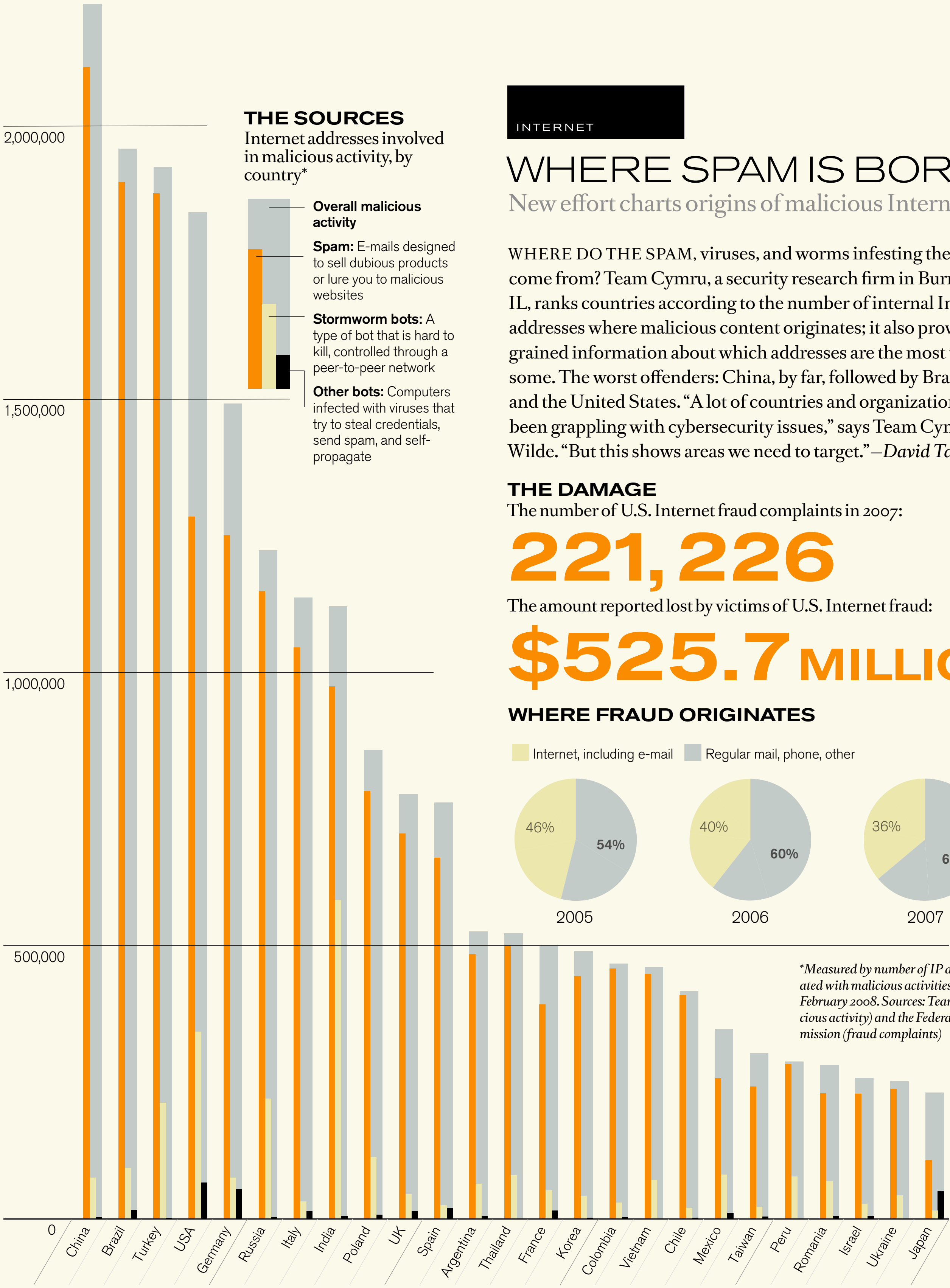
Existing methods for capturing carbon dioxide add huge costs

Power plant type	Added electricity cost with CO_2 capture	Capture technology
Natural gas	42 percent	Chemical solvents: carbon dioxide combines with amine compounds in a solution; heating releases the gas
Conventional coal	86 percent	Chemical solvents
Gasified coal	36 percent	Glycol-based substance absorbs carbon dioxide and releases it at lower pressure

Sources: National Energy Technology Laboratory, Stanford's Global Climate and Energy Project

THE SOURCES

Internet addresses involved in malicious activity, by country*



INTERNET

WHERE SPAM IS BORN

New effort charts origins of malicious Internet use

WHERE DO THE SPAM, viruses, and worms infesting the Internet come from? Team Cymru, a security research firm in Burr Ridge, IL, ranks countries according to the number of internal Internet addresses where malicious content originates; it also provides finer-grained information about which addresses are the most troublesome. The worst offenders: China, by far, followed by Brazil, Turkey, and the United States. "A lot of countries and organizations have been grappling with cybersecurity issues," says Team Cymru's Tim Wilde. "But this shows areas we need to target."—*David Talbot*

THE DAMAGE

The number of U.S. Internet fraud complaints in 2007:

221,226

The amount reported lost by victims of U.S. Internet fraud:

$525.7 MILLION

WHERE FRAUD ORIGINATES

Internet, including e-mail | Regular mail, phone, other

2005: 46% | 54%

2006: 40% | 60%

2007: 36% | 64%

**Measured by number of IP addresses associated with malicious activities in January and February 2008. Sources: Team Cymru (malicious activity) and the Federal Trade Commission (fraud complaints)*

TOMMY MCCALL

STARTUP

ALL THE INTERNET'S A GAME

Gamelayers makes a treasure hunt of everyday Web browsing

Justin Hall and Merci Hammon

A SAN FRANCISCO startup hopes to turn ordinary Web browsing into a massively multiplayer online game. In what Gamelayers calls PMOG (for "passively multiplayer online game"), players devise and follow "missions" that wind across websites (invisibly to nonplayers), leaving messages and prizes for one another. To get started, players download software that adds a toolbar to their Web browsers. When they log in to PMOG, software tracks their Web usage and gives them points for each top-level domain they visit within a 24-hour period. Those points buy tools that players can use to build missions, which can take many forms: a PMOG player might, for example, put a popup on the Boston Red Sox home page, inviting fellow players on a mission to learn about Red Sox history. At each site on the tour, a player following the mission would find a narrative written by the creator.

Along the way, players can send instant messages and links, leave gifts, and even plant little bombs that cause browser windows to temporarily (and harmlessly) shrink. "It's like instant messaging meets [social-bookmarking site] del.icio.us meets Wikipedia," says company investor Joichi Ito, a board member of the Mozilla Foundation and CEO of the venture capital firm Neoteny. Ito believes that Gamelayers will draw participants who grew up playing video games; as players devise new types of games and game components, Ito says, advertising strategies can evolve accordingly. Justin Hall, Gamelayers' CEO and cofounder, says advertisers could create missions that incorporate advertising messages: Warner Brothers, say, might promote the next Batman movie with a tour of the superhero's history.

Gamelayers

URL: www.gamelayers.com
Location: San Francisco, CA
Product: www.pmog.com
Founders: Justin Hall, Merci Hammon, Duncan Gough
CEO: Justin Hall
Number of employees: 5
Funding amount: $500,000
Funders: O'Reilly AlphaTech Ventures, Joichi Ito, Richard Wolpert

Similar ideas have been tried before. Third Voice, a short-lived startup that lasted from about 1998 to 2001, allowed users to annotate websites. Gamelayers' success "will depend on how well it avoids spam, both literally and figuratively, from people that you're not interested in hearing from," says Jonathan Zittrain, a professor of Internet governance and regulation at the University of Oxford, who was on Third Voice's advisory board. Zittrain adds that Gamelayers, like Third Voice, is likely to trigger "outrage from webmasters, who want to know that the site you see is the site they intend for you to see."

Gamelayers is now testing PMOG with a small group of users. Hall says that people can register for the beta version of the game now, though no date for its public release has been set. –*Erica Naone*

SUZY POLING


Technology
PUBLISHED BY MIT
Review
I am the future of technology.
GEORGE T. WHITESIDES
EXECUTIVE DIRECTOR, NATIONAL SPACE SOCIETY
SENIOR ADVISOR, VIRGIN GALACTIC
George Whitesides leads the efforts of the National Space Society, an international organization of more than 12,000 members that is dedicated to opening space for humanity. He is also the senior advisor to Virgin Galactic, Sir Richard Branson's space tourism venture. As an innovator, business leader, and industry influencer, George is molding the future of technology. For him, *Technology Review* is a must read. "You can get the news anywhere," he says. "*TR* is actually charting and mapping technology for the future. It's essential to me because I'm focused on where the future will bring us."
www.technologyreview.com/reader

TODD WRIGHT

SENSORS

THREE-MINUTE ANTHRAX SENSOR

BY USING live mouse immune cells, the BioFlash sensor can detect potential airborne bioterror agents in three minutes. Fans pull airborne particles into a disposable disc containing the mouse cells, which have been genetically engineered to emit blue light when exposed to one of six agents, including anthrax and smallpox. The glowing cells eliminate the need for sample preparation and for a separate imaging system. The U.S. government is already using the BioFlash for building security in the Washington, DC, area.

Product: BioFlash **Cost:** $29,970 for the system, $96 per disc
Source: www.innovativebiosensors.com **Company:** Innovative Biosensors

WIRELESS

WI-FI GOES LONG

ORDINARILY, hooking a Wi-Fi router up to a directional antenna lets you send a Wi-Fi signal a few kilometers. By modifying the router's software, however, Intel has increased that distance to as much as 100 kilometers. The modified software coördinates sending and receiving antennas, assigning each of them specific time slots for talking and listening. Routers that implement the new system will be connected to off-the-shelf directional antennas in India this fall, bringing Internet connectivity to remote villages.

Product: Rural Connectivity Platform **Cost:** Less than $500
Source: blogs.intel.com/research/2008/03/rural_connectivity_platform_be.php **Company:** Intel

INTERFACES

Mind-Reading Game Controller

THE NEW video-game controller from Emotiv Systems is a wireless headset with 16 embedded sensors that register electrical signals from the brain. The device can detect users' facial expressions and emotions, potentially giving digital characters the personalities of their creators. Once the headset is calibrated to a player's brain signals, the player can push, pull, lift, and drop virtual objects using thoughts alone. The device comes with a game designed to explore the possibilities of brain-controlled gaming, but it can be adapted to any PC game.

Product: Epoc headset
Cost: $299
Source: www.emotiv.com
Company: Emotiv

ROBOTICS

PERFECT PANORAMIC PHOTOS

FORGET THOSE measly megapixel images your digital camera takes. The Gigapan robotic camera mount—the product of a partnership between NASA, Google, Carnegie Mellon University, and Charmed Labs of Austin, TX—lets you precisely pan and tilt your camera so that photos can be digitally stitched together into seamless *gigapixel* panoramas. At Gigapan.org and in Google Earth, you can explore hundreds of panoramas uploaded by participants in the Gigapan product trial.

Product: Gigapan imager (beta test unit pictured) **Cost:** Under $400 **Source:** www.charmedlabs.com **Company:** Charmed Labs

JOSHUA SCOTT (WI-FI AND GIGAPAN); COURTESY OF EMOTIV (HEADSET)

MASSACHUSETTS INNOVATION
& TECHNOLOGY EXCHANGE

WHAT'S NEXT.

5^{th} Annual MITX What's Next Forum & Technology Awards Ceremony

Celebrating Innovation in Technology

Analytics & Business Intelligence
Collaboration & Social Networking
Content Management
Data Management
Enterprise Technologies
Marketing/Customer Relationship Technologies
Mobile
Video
Virtual Reality/Gaming

The MITX Technology Awards recognize innovative technologies developed in the New England area, as well as the individuals and organizations responsible for driving these advancements.

Tuesday, June 3rd

5:30 pm – 8:30 pm

Royal Sonesta Hotel, Cambridge

- 5:30 -7:00 Registration, Cocktail Reception & Technology Demo
- 7:00 – 7:30 What's Next Forum
- 7:30 – 8:30 Awards Ceremony & Keynote Address

Innovation Hall of Fame Honoree : Dr. Amar Bose, Chairman & Founder, Bose Corporation

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Print design by Dean Whitney - Digitas

AUTOMOTIVE

LITHIUM-ION ELECTRIC CAR

LIGHT AND compact lithium-ion batteries sound great for electric vehicles—aside from their historical tendency to catch fire. But recent advances in electrode chemistry have made them much safer. One of the first vehicles to use the new batteries comes from a Norwegian company, Think. By year's end, Think plans to start selling ultracompact electric cars with a range of more than 100 miles. A123 Systems of Watertown, MA, and Indianapolis's EnerDel will provide the batteries.

Product: Think City electric car
Cost: About 20,000 euros
Source: www.think.no
Company: Think Global

COMPUTER VISION

SMART SECURITY CAMERA

SECURITY CAMERAS churn out so much data that they can overwhelm storage facilities and clog networks, but most of that data is pretty boring. Thanks to novel computer vision and machine-learning algorithms, VideoIQ's cameras can tell when something suspicious or unusual is happening on screen. At that point, they start recording at a higher resolution and send an alert over the network. Otherwise, they record at such low resolution that they can store months of footage locally, saving disk space and network bandwidth.

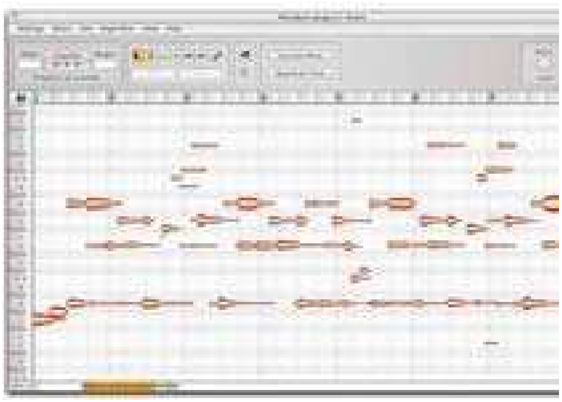
Product: VideoIQ iCVR (intelligent camera with video recording) **Cost:** $1,289 wholesale **Source:** www.videoiq.net/products **Company:** VideoIQ

DIGITAL AUDIO

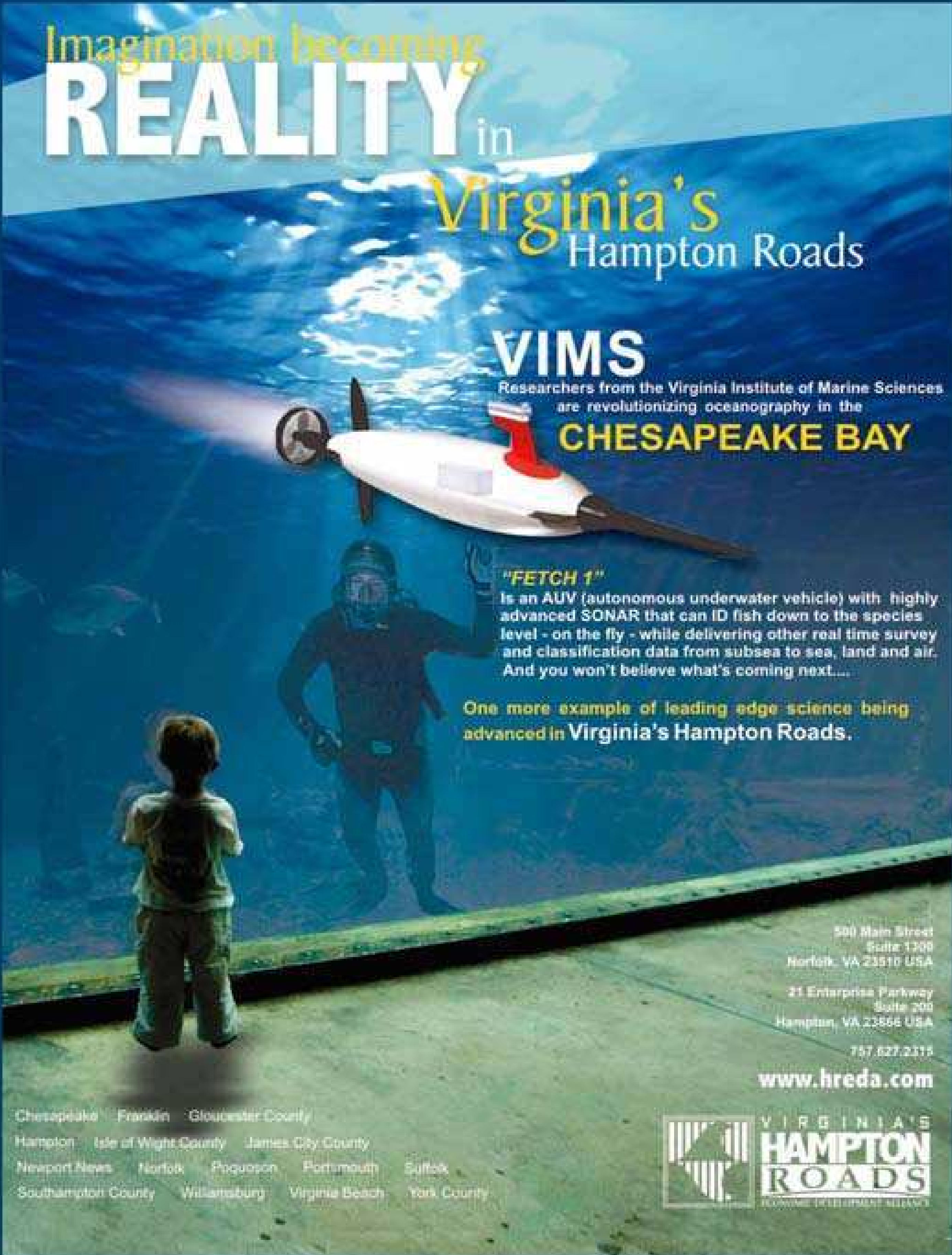
Sound Separator

POP STARS with more charisma than talent have long enjoyed the benefits of software that corrects out-of-tune notes in recorded performances. But that software has worked only with notes that sound one at a time, as in a vocal line or a sax solo. New technology from the German company Celemony, however, can pull apart notes played at the same time—on different strings of a guitar, for instance—and modify them individually. The software even works in real time, for live variation of recorded loops.

Product: Direct Note Access **Cost:** Included in Celemony's $399 Melodyne plug-in, or a $129 upgrade for existing Melodyne customers **Source:** celemony.com **Company:** Celemony



COURTESY OF THINK (CAR); JOSHUA SCOTT (CAMERA); COURTESY OF CELEMONY (SOUND)



Imagination becoming
REALITY in
Virginia's
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VIMS
Researchers from the Virginia Institute of Marine Sciences are revolutionizing oceanography in the
CHESAPEAKE BAY
"FETCH 1"
Is an AUV (autonomous underwater vehicle) with highly advanced SONAR that can ID fish down to the species level - on the fly - while delivering other real time survey and classification data from subsea to sea, land and air. And you won't believe what's coming next....
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HAMPTON
ROADS

ROBOTICS

NEXT THING TO BEING THERE

IT MAY look like the popular Roomba vacuum cleaner as it scoots across the living-room floor, but iRobot's new ConnectR is actually a way for people to interact with distant relatives or pets. The robot is equipped with a Wi-Fi antenna, a speaker, a microphone, and a tilting, zooming video camera. A remote user can pilot the robot over the Internet, carrying on long-distance conversations and watching video of live events.

Product: ConnectR Virtual Visiting Robot **Cost:** Around $500 in a mid-2008 pilot program **Source:** www.irobot.com **Company:** iRobot

CELL PHONES

All-Purpose Handheld

STRIPPED naked, the Modu is slightly larger than a domino, with a small screen, a seven-button keypad, and one gigabyte of data storage. It's a working cell phone, but it can also be popped into larger gadgets—called "jackets" and "mates"—that borrow its wireless connection, processor, and stored data. Mates are things like PDAs and GPS receivers that work fine on their own; jackets work only with the Modu inside and are mostly larger phones with added features and bigger screens.

Product: Modu
Cost: Around 200 euros for a base unit and two jackets
Source: www.modumobile.com
Company: Modu

HOUSING

OFF-THE-GRID HOUSING

IF YOU'RE worried about dependence on fossil fuels, the RuralZed timber-frame kit house can make you self-sufficient. The house's energy-conserving features include south-facing windowed walls, a solar-thermal water heating system, natural ventilation that exploits air pressure differentials, heat-absorbent cement or masonry walls and floors, and an airtight polymer membrane that seals seams and joints. Thanks to the resulting savings, the house's energy requirements can be met by roof-mounted solar panels and specially designed wind turbines that rotate around a vertical axis.

Product: RuralZed **Cost:** About $240 per square foot for the basic house (erected), $280 per square foot with all the options (erected) **Source:** ruralzed.com **Company:** ZedFactory

JOSHUA SCOTT (CONNECTR); COURTESY OF MODU (PHONE); COURTESY OF ZEDFACTORY (HOUSING)

Q&A

JENNIFER CHAYES

Understanding online networks

When Jennifer Chayes left her job at the University of California, Los Angeles, in 1997 to become a researcher at Microsoft's labs in Redmond, she declared that it would take 100 years for her academic work to find real-world applications. But as managing director of the newly announced Microsoft Research New England lab in Cambridge, MA, she has parlayed her background in mathematical physics into research with broad implications for today's Internet.

To Chayes, the trails left by countless social and business interactions on the Internet amount to enormous math problems. Solving those problems, she believes, will help computer scientists create online tools, such as search engines and social networks, that are more efficient and effective.

TR assistant editor Erica Naone met with Chayes at the still-empty offices of her new Cambridge lab to learn how a mathematician understands the Internet.

***TR*: What is the common theme in your research?**

Chayes: I'm particularly interested in self-organized networks, such as the World Wide Web and social networks. In self-organized networks, people or entities choose to enter the network on their own. There's not some authority dictating the structure of the network, so that structure is constantly evolving.

Can you give me an example of how you try to understand a network?

There's a whole area called game theory, which takes into account that people are selfish agents. [It also models their interactions and the possible outcomes, attempting to define the best result for each "player."] Now researchers are starting to study game theory on networks, modeling the complex interactions among many selfish agents. Understanding the possible outcomes and behaviors of these networks is one of the next big mathematical challenges.

Are there examples?

[Online] advertisers bidding on a variety of keywords. Each advertiser is a self-interested party interacting with all other advertisers who bid on the same keywords. Each advertiser has a valuation for each word, and an overall budget. Since we don't know how to deal with the repeated game on the network implicit in this set of interactions, we just do a separate auction on each keyword to assign ads to search words. Maybe if we could deal with some of these problems mathematically, we could come up with something that was actually more efficient than these separate auctions—better for the advertisers, better for the customers, better for the search engines.

How would that help?

If we more efficiently match up ads with queries when we perform the ad auctions, then the consumer is more likely to get what he or she is seeking, the advertiser is more likely to generate maximum sales per ad dollar, and the search engine is more likely to generate the maximum revenue per search. No search engine comes close to the optimum today. So there's a lot of room for improvement.

Where else might your work help?

I think that recommendation systems are going to be as important as search algorithms *[see "Recommendation Nation," p. 82]*. In a recent piece of work, we came up with a list of desired properties for a recommendation system, and what we ended up doing was proving mathematically that there is no possible recommendation system that has all these desired properties. So I would have to choose which properties I am willing to give up and design recommendation systems that preserve the properties I want most.

What kinds of properties?

There's transitivity. If I trust the recommendation of person B, and person B trusts the recommendation of person C, then I should trust the recommendation of person C.

What about privacy? Can recommendation systems still let users keep control?

Those are exactly the kinds of questions that we're asking. We didn't consider privacy in our work, but one could definitely add privacy to the list of properties, and then it might be possible to come up with a theorem saying, for example, you can't have a recommendation system that will deliver all the information you want and have all the privacy.

How might this research change the way we use these applications?

It could be that at some point somebody could go onto a social network and say, "Here are the properties that I want for my recommendation system," and a different person could go in and say, "Here are the properties that I want," and they could get two different recommendation systems. In a similar way, search engines have been around for a while, but I think they're still very far from exactly what we want, and over time we'll be able to come up with search engines which are much more personalized. Then we would also have to figure it out on the back end. Can we accommodate all these different algorithms? I hope that at some point computations would be done differently for your search engine and recommendation system and for mine. TR

WWW

Hear Jennifer Chayes's ideas on Microsoft's Cambridge research lab: **technologyreview.com/microsoft**.

Photograph by MARK OSTOW

PHOTO ESSAY

THE MAKING OF A NEW COLLIDER

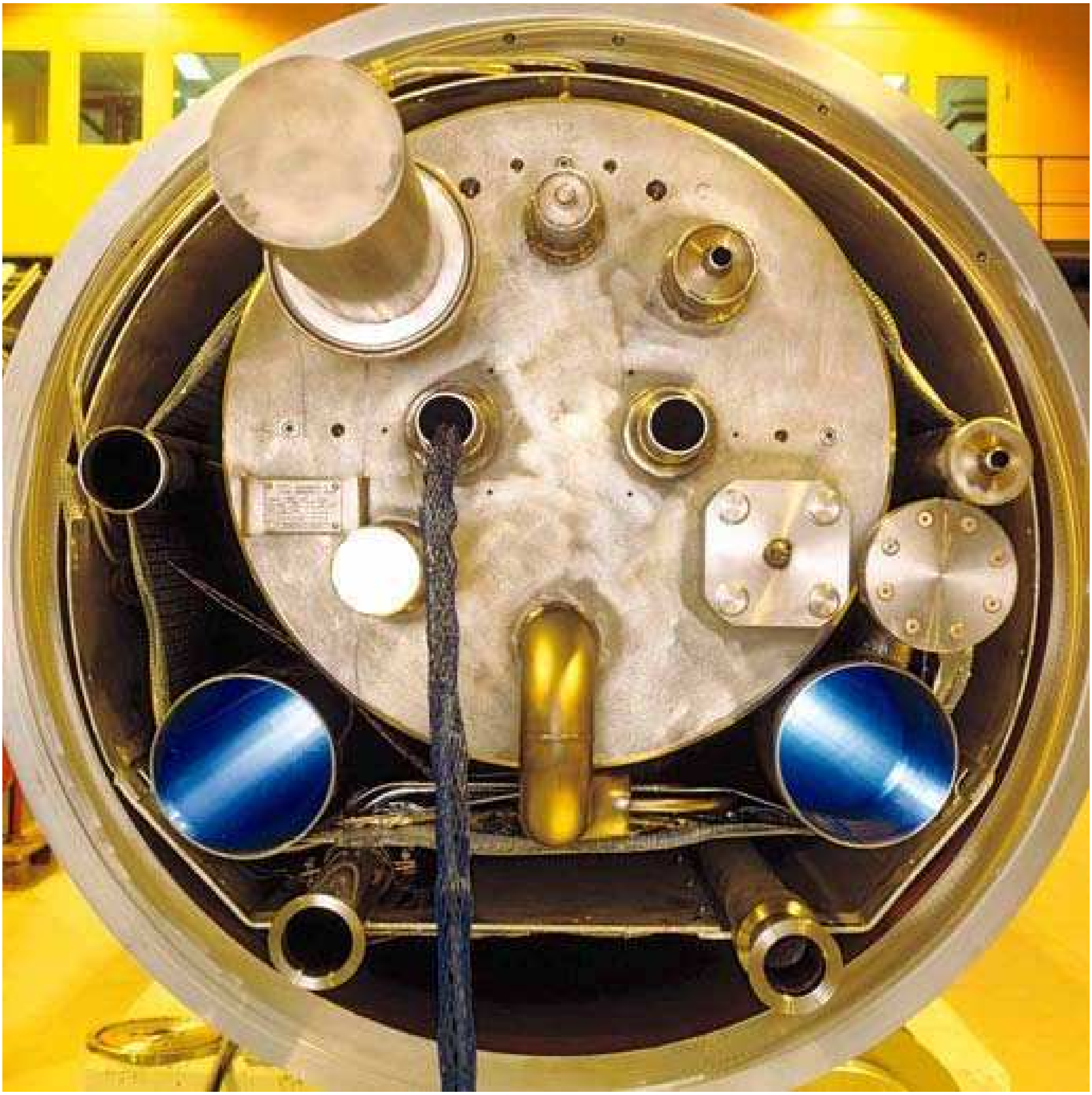
The biggest physics experiment ever, CERN's Large Hadron Collider (LHC), goes live this summer. The international project, whose design was approved in 1994, cost over $6 billion. Thousands of powerful magnets, cooled by tons of liquid helium to 1.9 Kelvin (just above absolute zero), will guide two beams of protons as they travel in opposite directions around a 27-kilometer tunnel at close to the speed of light; then magnets at two locations will pull the beams together for the highest-energy particle collisions ever achieved. By identifying the products of these collisions, physicists hope to test the standard model of physics and discover new subatomic particles. (Read Nobel laureate Jerome Friedman's thoughts on the LHC in Notebooks, page 10.)

By KATHERINE BOURZAC

PRECISION BEFORE COLLISION

The compact muon solenoid (CMS), one of the LHC's main detectors, is made up of 11 conjoined pieces; each has layers of detectors tuned to find different particles that might result from proton collisions, including muons and electrons. This piece weighs 1,270 metric tons and was lowered from above ground to the bottom of the tunnel, 90 meters below, with mere centimeters of clearance. It took 11 hours.

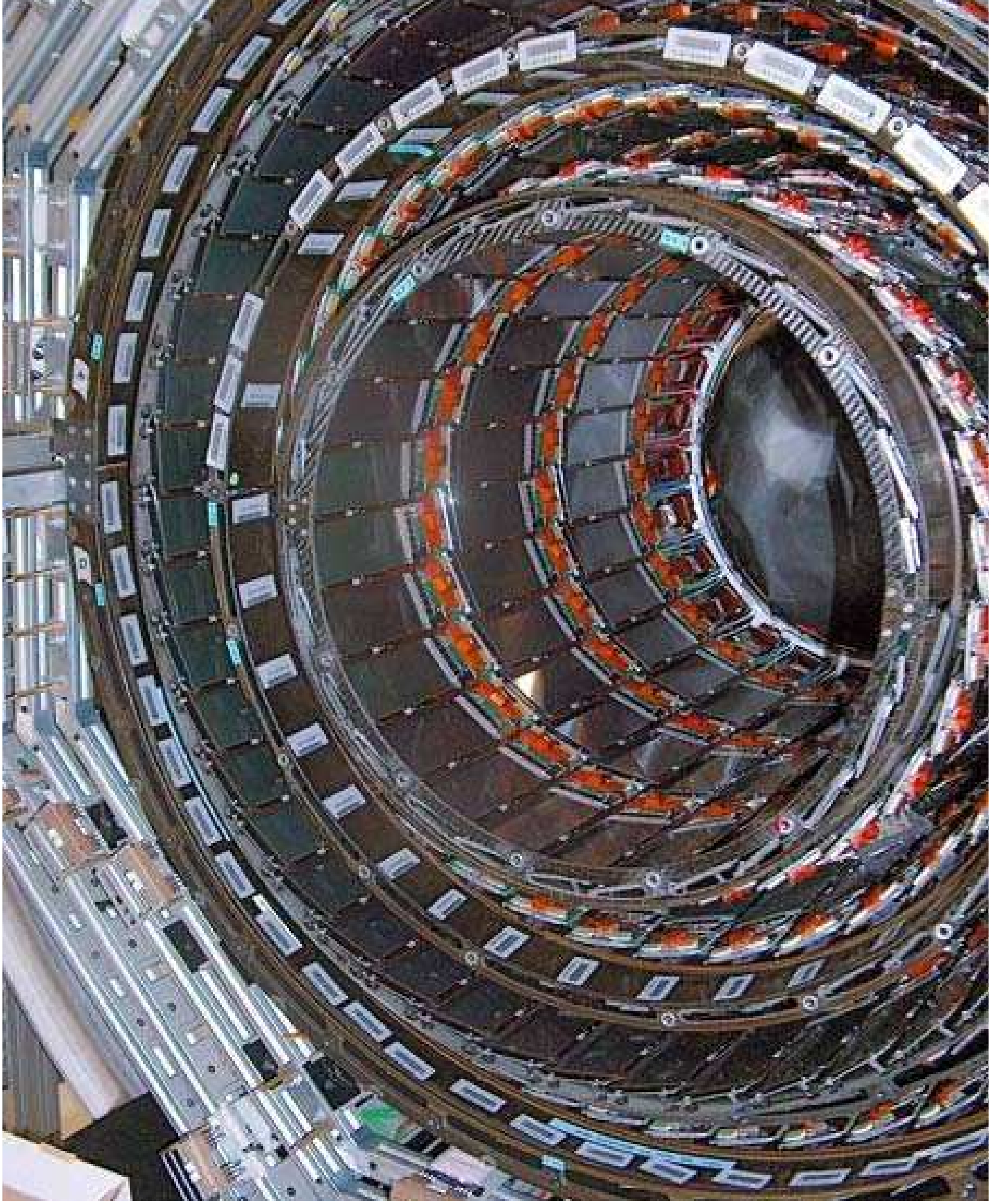
CERN



AP/KEYSTONE/MARTIAL TREZZINI (TUNNEL); AC TEAM (MAP); DAVID PARKER/SCIENCE PHOTO LIBRARY (MAGNET)

27 KILOMETERS OF MAGNETS

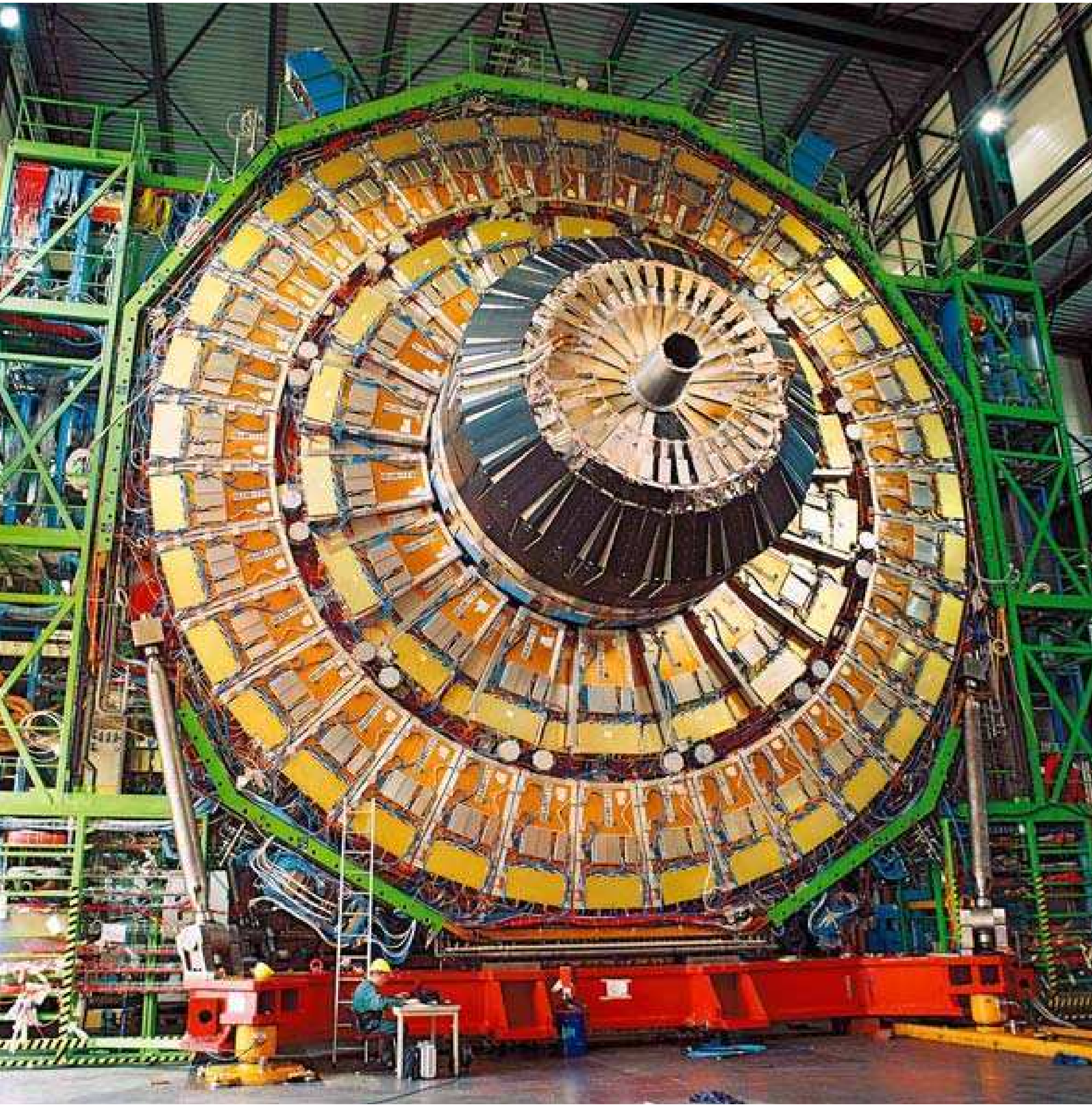
The two beams of protons will speed through their underground tunnels at a site straddling the border between France and Switzerland (this page, bottom). The tubes at far left house the high-power magnets that guide the beams. Above, a side view shows the channels through which the beams will accelerate (openings at center of image, one with a cable dangling from it). These two pipes are surrounded by superconducting metal cables (not visible in this image) through which a tremendous electric current flows, creating strong magnetic fields that guide the protons around the LHC and then toward each other for the high-energy collisions. Two tubes for the liquid helium that cools the magnets are visible at the bottom of the cross section.

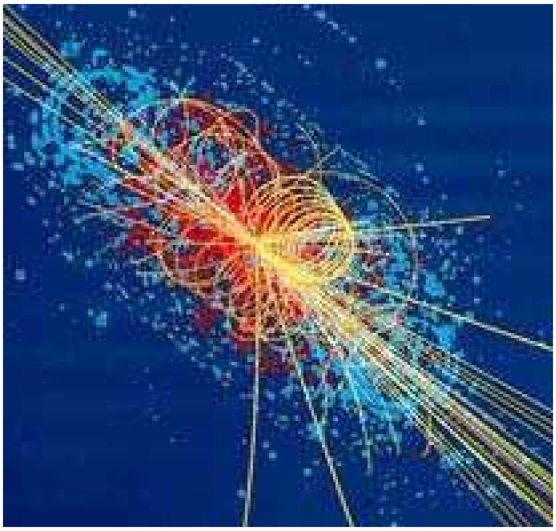


CMS DETECTORS

The CMS is named for its compact magnet, called a solenoid because of its coiled shape, and for one of the particles it specializes in detecting, the muon. When protons collide inside the CMS, the magnet at its heart (metal collar, this page, bottom) deflects the resulting subatomic particles so that their paths intersect with many layers of detectors. Layers of silicon tiles inside the inner tracker barrel (above), which nests inside the magnet, pinpoint the location of charged particles and measure their momentum. The protruding barrel of the piece at far right also fits inside the magnet's hollow. The rings of gold-colored boxes are muon chambers that will detect the particles.

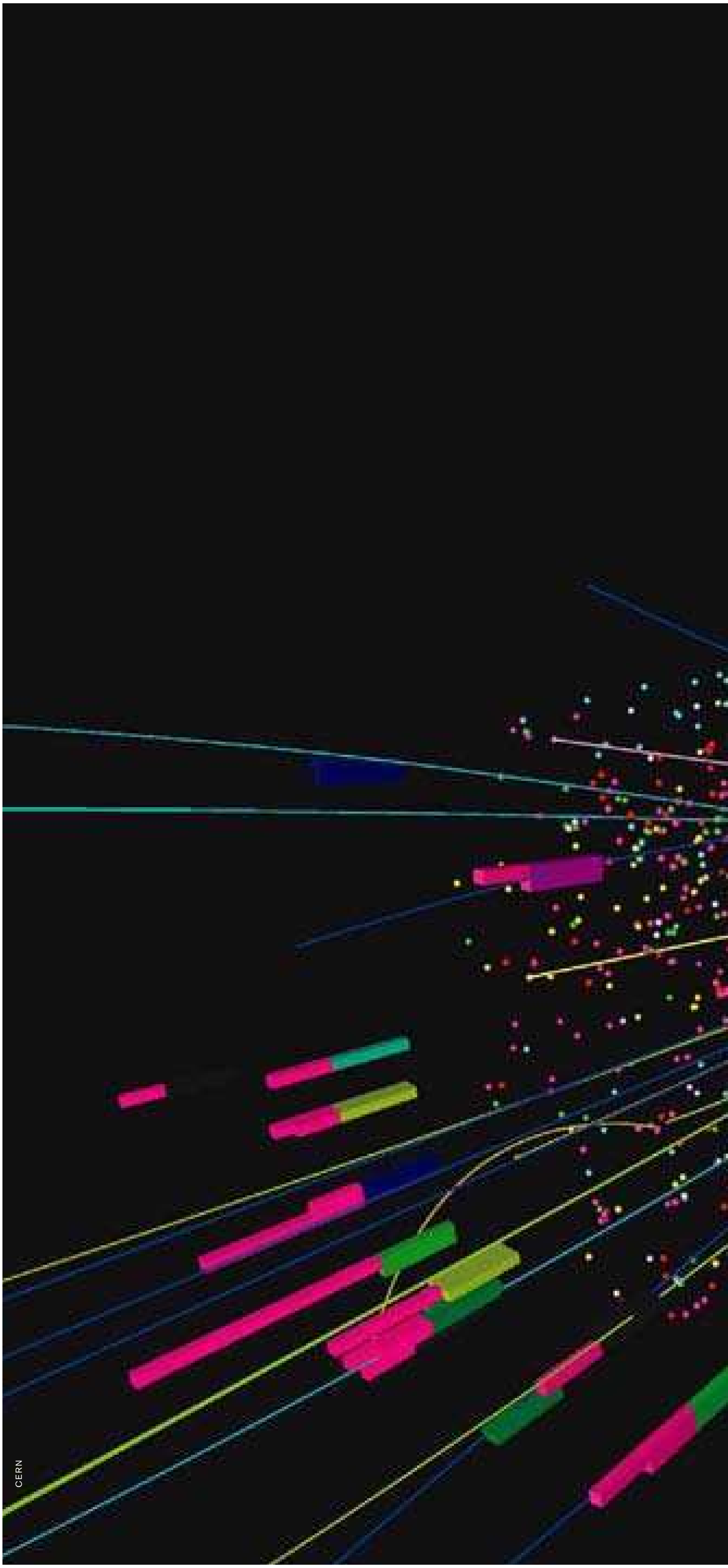
CERN (SILICON); MAXIMILIEN BRICE, CLAUDIA MARCELLONI (MAGNET); PATRICE LOIEZ (BARREL, RIGHT)



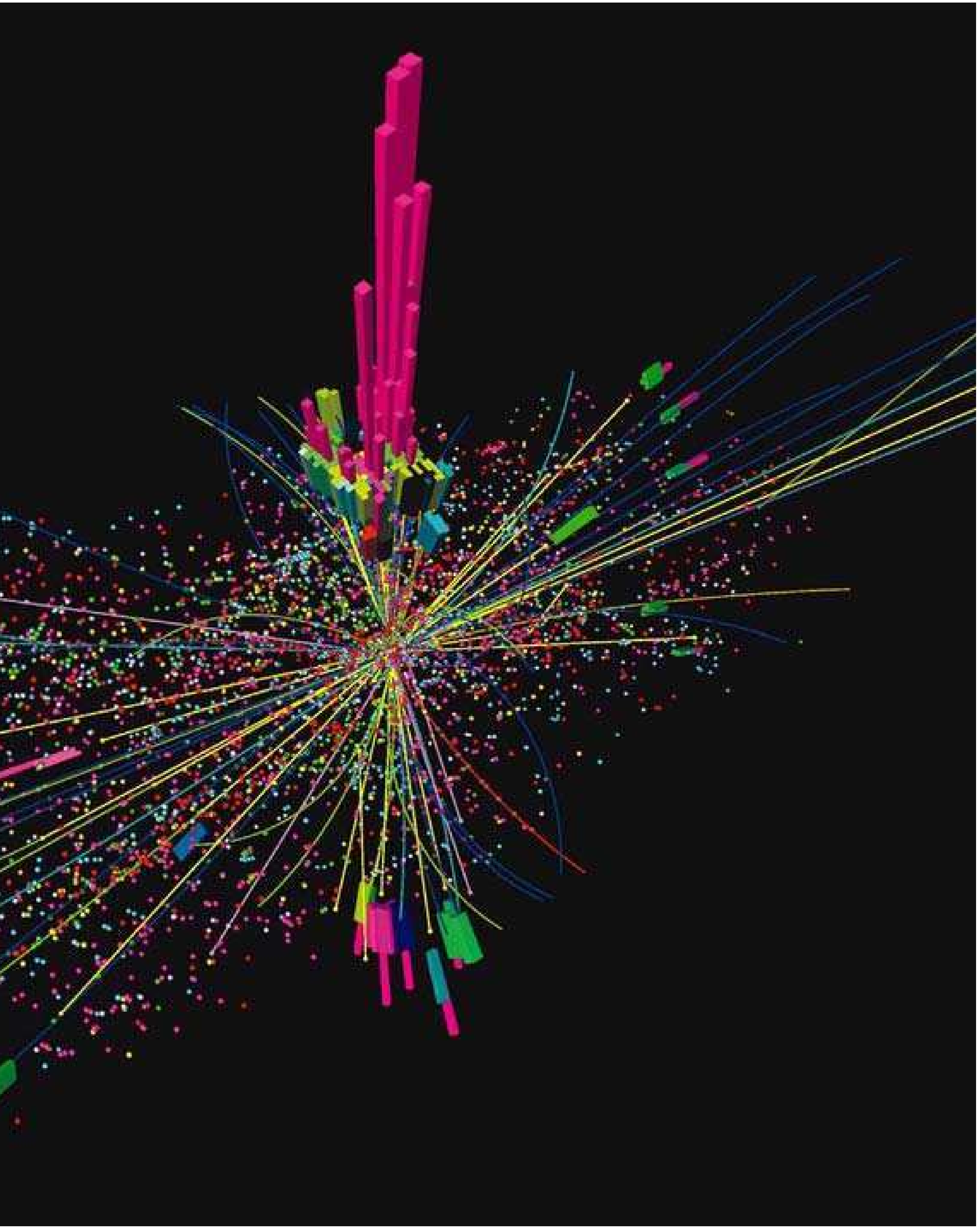


PICTURING HIGGS AND Z PRIME

Data gathered inside the CMS and other detectors will be reconstructed as event visualizations like the hypothetical ones pictured here. In these images, the dots represent ionization signals left by particles traversing a detector. Software picks through the data to trace particles' paths, represented as lines. The existence of newly observed particles is inferred if the products they decay into are detected. One of the particles likely to be detected by the CMS in its early days is called Z prime, says MIT particle physicist Steven Nahn; the evidence it leaves behind is thought to include two easy-to-detect particles, muons and electrons. At right is a visualization of a Z prime decaying into jets of energetic particles, represented by the rectangular beams. The image above is a visualization of a Higgs boson decaying into four muons. The curly lines represent particles with low momentum that don't reach the farthest detectors. Providing evidence of the Higgs boson, a hypothesized particle that is thought to explain why particles have mass, would be a major coup for the LHC.



CERN



AFTER THE BLAST
Stephen Kinney, a U.S. National Guard sergeant, survived a roadside blast while serving in Iraq in 2004. After he returned home, his mild traumatic brain injury went undiagnosed for months.

Brain Trauma in Iraq

THOUSANDS OF U.S. SOLDIERS HAVE SURVIVED POWERFUL EXPLOSIONS IN IRAQ. MANY ARE RETURNING HOME WITH BRAIN INJURIES THAT COULD RESULT IN LONG-TERM DISABILITIES.

By EMILY SINGER

A few days into his tour of duty at the 86th Combat Support Hospital in Baghdad, Colonel Geoffrey Ling, a U.S. Army neurologist, noticed something unusual. Soldiers who had sustained severe head injuries in blasts from improvised explosive devices (IEDs) appeared to be in much worse shape than he would have expected given his experience with patients who had suffered seemingly similar injuries in car accidents and assaults. The brains of the injured soldiers were swollen and appeared "a very angry red," he recalls. Some soldiers were conscious and could talk normally but were stumbling around the hospital, unable to keep their balance. "Their [brain] scans were stone-cold normal, and when you talked to them, they seemed fine," says Ling, who is now a staff physician at Walter Reed Army Medical Center and a program manager in the Defense Sciences Office at the U.S. Defense Advanced Research Projects Agency (DARPA) in Arlington, VA. "But when I started testing them, like asking them to do addition, they were clearly not normal."

By the time Ling arrived in Iraq, in 2005, thousands of U.S. soldiers had experienced IED attacks. While many of them had survived the concussive blasts, Ling and other physicians had begun to notice that a worrisome number were showing signs of brain damage. Ling, who is a neuroscientist as well as a neurologist, was puzzled. "Why does this injury look different?" he wondered. "What is it in the blast that's causing it—the pressure, the noise, the cloud of fume?" After months of treating blast wounds in both American troops and Iraqi security forces, Ling had returned from his tour determined to wage war on brain injury. He knew that the answers to these questions could be crucial to protecting soldiers in the field and screening and treating them when they came home.

Traumatic brain injury has been called the signature injury of the Iraq War, in which increasingly powerful IEDs and rocket-propelled grenades are the insurgents' weapons of choice. Because they produce such powerful blasts, these weapons often cause brain injuries. Meanwhile, thanks to better body armor and rapid access to medical care, many soldiers whose injuries would have been fatal in previous wars are returning alive—but with head trauma. "With IEDs, the insurgents have by dumb luck developed a weapon system that targets our medical weakness: treating brain injury," says Kevin "Kit" Parker, a U.S. Army Reserve captain and assistant professor of biomedical engineering at Harvard University who served in southern Afghanistan in 2002. Doctors do not yet fully understand brain injuries, particularly those caused by blasts, and no effective drug treatments exist. Early evidence suggests that explosions, which account for nearly 80 percent of the brain injuries identified at Walter Reed, cause unique and potentially long-lasting damage.

The extent and impact of the brain-injury epidemic are not yet clear, though the U.S. Congress appropriated $300 million last year for research into traumatic brain injury and post-traumatic stress disorder. The U.S. Department of Defense reports that

CHRISTOPHER CHURCHILL

approximately 30 percent of those evacuated from the battlefield to Walter Reed Army Medical Center have traumatic brain injury (TBI). The problem is probably worse than that: the DOD figure does not include brain injuries in soldiers whose wounds were not severe enough to require evacuation or whose injuries were not identified until after they completed their tours. Post-deployment surveys suggest that 10 to 20 percent of all deployed troops have experienced concussions. At worst, thousands of service members could return home with long-lasting problems, ranging from debilitating cognitive deficits to severe headaches and depression to subtler personality changes and memory deficits.

Military doctors are only beginning to get a grasp on the number of soldiers who have suffered mild traumatic brain injury, the medical term for a concussion. Mild injuries are by far the most common type of brain trauma, but they are more easily missed than moderate and severe injuries (they typically don't show up on standard brain scans), and the lasting effects, especially of repeated concussions, are not yet clear. Surveys of troops to be redeployed in Iraq suggest that 20 to 40 percent still had symptoms of past concussions, including headaches, sleep problems, depression, and memory difficulties. "We don't know what it means in terms of long-term functional ability," says William Perry, past president of the National Academy of Neuropsychology.

AN ORANGE FLASH

In November 2004, Stephen Kinney, a U.S. National Guard sergeant from North Chelmsford, MA, was patrolling a main supply route through southern Iraq when a buried artillery shell exploded outside the door of his Humvee. The blast propelled the vehicle into the air, riddling the doors with shrapnel. "All I remember is a big orange flash," says Kinney, who was thrown against the Humvee's radio, then against the ceiling, and briefly lost consciousness.

More concerned about a bruised hip and swollen shoulder than about his head, Kinney never considered the possibility of brain injury. The doctor who treated him at a military field hospital in Iraq didn't ask him about losing consciousness, or about his state of mind after the blast. "There were marines coming in from Fallujah with their arms blown off," says Kinney. "They figured if you weren't bleeding and had all your limbs, you were doing okay."

It wasn't until months after Kinney's return home the following February that he saw a psychiatrist at the local VA hospital and was evaluated for brain injury. He underwent extensive neuropsychiatric testing, which assessed cognitive capacities such as memory, attention, and higher-order reasoning, and he was diagnosed with mild traumatic brain injury. When Kinney returned to his job with the post office, he began to notice problems. He had trouble remembering names and numbers and often forgot whether he had scanned the bar codes on mailboxes along his route, as mail carriers do every 30 to 60 minutes to log their progress. In addition, though he'd been an avid illustrator (while on duty in Iraq he drew a Christmas card depicting a Humvee parked under a decorated palm tree), he hasn't taken up his colored pencils since he returned.

Despite the designation "mild," even a single concussion can produce serious symptoms, including severe headaches, difficulty sleeping, problems with memory and concentration, and even changes in personality. "The spouses say, 'He is totally different—he used to be a quiet guy and now he's agitated,' or 'He used to be energetic and now has no motivation,'" says Jeffrey

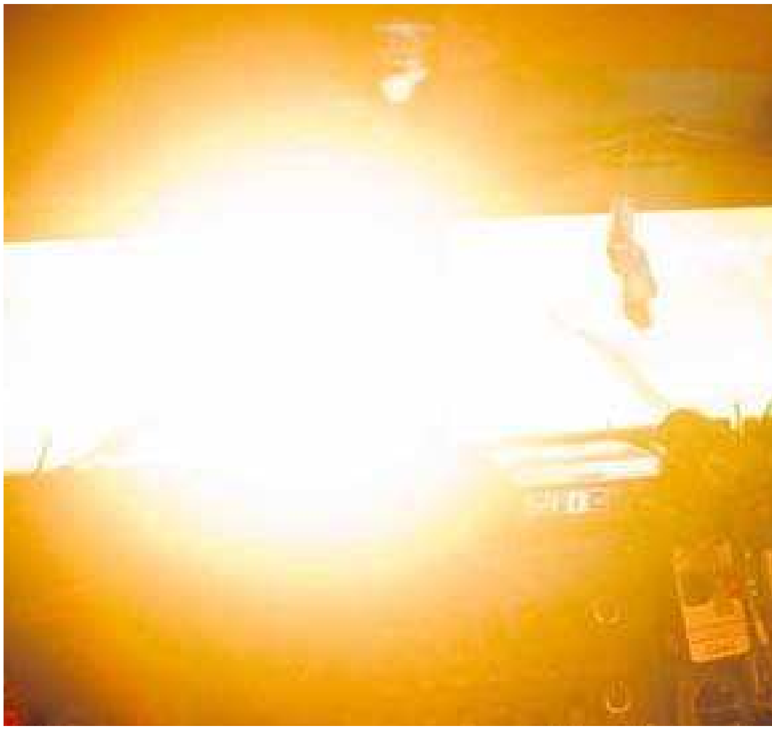
THE VIEW FROM INSIDE Improvised explosive devices (IEDs) in Iraq are often buried on roadsides and remotely detonated when convoys of military vehicles pass by. Here, a navy unit that disposes of explosives snaps pictures of a detonating IED from inside a mine-resistant vehicle.

Barth, a neuropsychologist at the University of Virginia School of Medicine in Charlottesville who has done pioneering work in the study of concussion. "They can also lose the ability to put everything together and to make good judgments." About half of people who suffer concussions quickly recover. But in the rest, symptoms can linger indefinitely. About 10 percent of concussion victims have problems severe enough to interfere with daily life and work. "No one knows how to treat it, how long it lasts, and

When Kinney's Humvee was blown up, his brain was subjected to the acceleration and rotational forces of a car crash. But he also felt the forces unique to blasts—the massive pressure wave, the electromagnetic pulse, and the light, heat, and sound emanating from the explosion, all of which may ravage the brain.

ANATOMY OF AN EXPLOSION

In Iraq, an IED is often buried near a road or hidden in a car and then triggered remotely. Detonating the device sets off a chemical reaction in which anywhere from a few to hundreds of kilograms of explosive expel their energy in a microsecond, compressing the surrounding air into a powerful shock wave. The explosion can also produce an electromagnetic pulse, a wave of electric and magnetic fields that may cause surges in current and voltage. Though blasts and the resulting injuries have been part of warfare for a long time—after the Napoleonic wars, some speculated that people who mysteriously died near firing cannons were injured



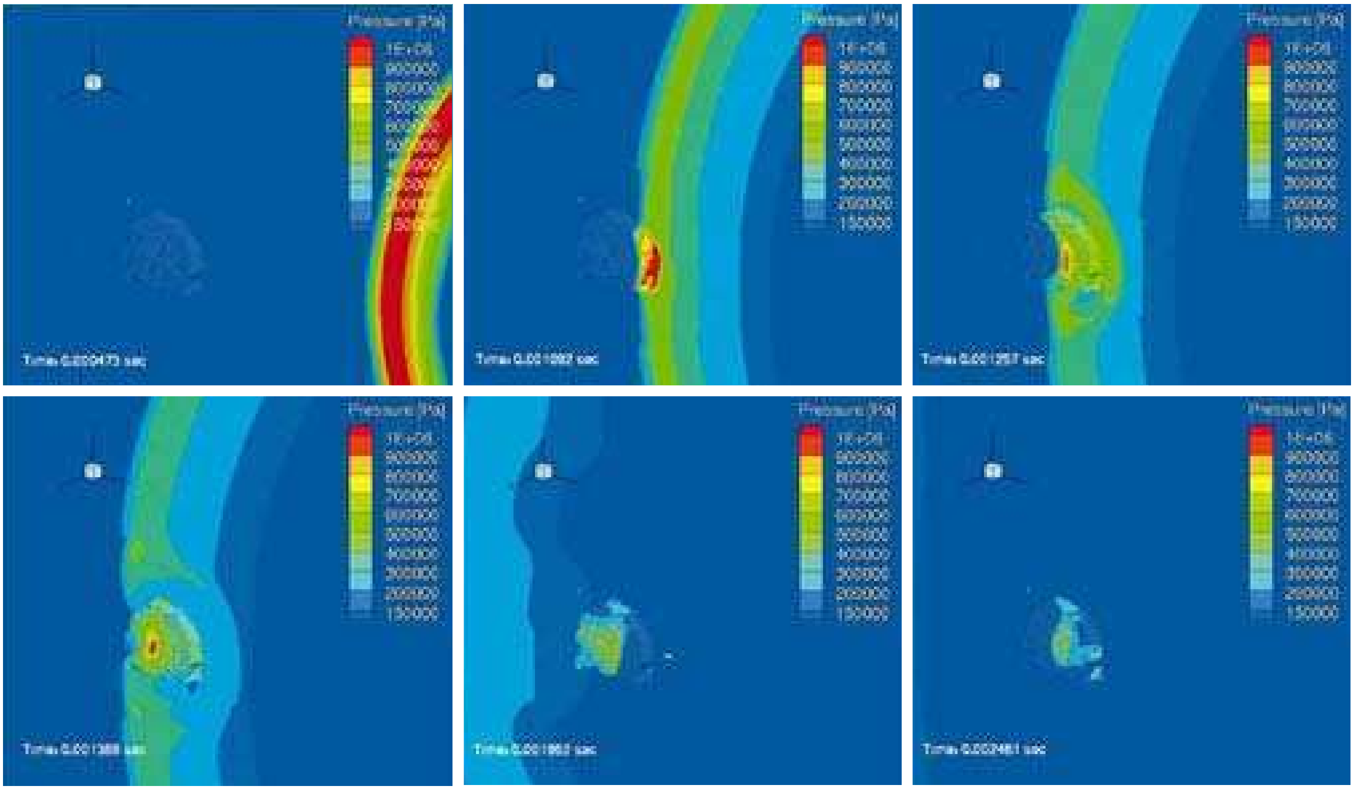
DANFUNG DENNIS/WPN

whether it's safe to leave someone deployed," says Jon Bowersox, chief of surgery at the Cincinnati VA Medical Center and a colonel in the U.S. Air Force Reserve.

Especially worrying is the prospect that troops in Iraq will suffer repeated concussions, reinjuring their brains while they're still in a vulnerable state. For soldiers patrolling highways and guiding convoys, exposure to multiple blasts is a given; some have reported encountering tens of blasts in a day. In rare cases, multiple concussions in quick succession can lead to serious injury. But subtler damage may also accumulate, leading to depression and cognitive decline. "It's still an open question," says Barth. "How many concussions can you have without having a really bad outcome down the road?"

by excessive vibration in the air—little is known about exactly how a blast wreaks havoc on the brain. (Before newer types of body armor were available, soldiers exposed to blasts often died of lung injury when pressure waves ruptured air-filled tissue; so blast research has largely been concerned with the lungs rather than the brain.)

Most studies of concussion have focused on blunt trauma, as in a blow to the head, not the effects of blasts. To complicate matters, an explosion can cause multiple types of brain injury. For example, when Kinney's Humvee was blown up, his brain endured the type of rapid acceleration and rotational forces typically seen in a car crash. Such forces, which can send the brain bouncing around inside the skull, can twist or tear axons—the long, thin fibers that



SHOCKING THE BRAIN

Computer simulations are helping scientists identify the parts of the brain most vulnerable to blast injury. This series of images shows a simulated pressure wave (originating in the right side of the first image) hitting the front of the virtual head (center, shown here cut in half), with the highest pressure levels shown in red. The pressure wave ricochets around the tissue as it's deflected by different brain structures and continues to propagate inside the brain even after the pressure wave in the air has passed (last two frames).

DEFENSE AND VETERANS BRAIN INJURY CENTER

connect nerve cells—and induce bleeding and swelling in the brain. But Kinney also felt the forces unique to blasts: the massive pressure wave, the electromagnetic pulse, and the light, heat, and sound from the explosion, all of which may ravage the brain in ways that haven't been fully documented.

To better understand what a blast does to the brain, Raul Radovitzky, an associate professor of aeronautics and astronautics at MIT, and David F. Moore, a neurologist at Walter Reed Army Medical Center who has a doctorate in fluid dynamics, developed a software model incorporating both the physics of pressure waves and the variable properties of the brain's tissues. Through magnetic resonance imaging, Moore modeled 11 features of the head, including the skull, the cerebrospinal fluid, the brain's fluid-filled ventricles, the sinuses, the brain's layer of white matter, and even the fat layer surrounding the eyes. The researchers used that information to create a computer model of the head, which they subjected to a simulated blast, observing how energy transferred from the air to the head affects the different structures. The model highlights the parts of the brain that endure the greatest stress and are thus most vulnerable to injury.

A movie of one simulation shows a rainbow-colored pressure wave propagating through a cross-sectional slice of the head, ricocheting off the skull, and rippling through the brain seemingly at random. So far, using values approximating a pressure wave that would damage the lungs, the model indicates that pressure from a blast far exceeds the minimum level thought to induce impact-related brain injuries. The researchers have also determined that tissue interfaces, such as the boundary between bone and brain, reflect the waves, so those areas are at greater risk. The pressure wave appears to enter the brain predominantly through the eyes

and sinuses, and to a lesser extent through the skull, an observation that could influence the design of protective gear. Radovitzky and Moore are testing a new version of the model that includes a helmet, to evaluate how well it shields against the blast wave. "Blast protection for the head has not been a consideration in the design of body armor," says Radovitzky. "Maybe a small change to the armor could mediate the damage."

Across the Potomac River at DARPA, Geoffrey Ling has embarked on a similar quest to determine how blasts injure the brain. But unlike Radovitzky and Moore, whose computer model focuses on the pressure wave and its interaction with brain tissue, Ling and his colleagues are using animals, mostly pigs, to study the damage inflicted by each component of the blast: heat, sound, light, pressure wave. "We want to figure out what in that dirty environment causes [the most] injury," Ling says. "Say it's pressure or sound. Then we can go back and look for strategies to defeat them."

The pigs are immobilized in harnesses and then exposed to an explosion powerful enough to cause moderate to severe brain injuries. Since the animals will not be thrown against a wall or hit with debris, the scientists can study the effects of the explosion in isolation. "When exposed to a survivable blast, they have difficulty walking that lasts for days," says Ling. The explosions also disrupt appetite—all symptoms that mimic those reported by soldiers with blast-induced concussions.

But another finding is surprising. Most scientists have assumed that blast-related injury comes from the pressure wave. Preliminary studies from the DARPA program seem to contradict that hypothesis. When pigs were put into a specialized wind tunnel that generates shock waves like those accompanying blasts, the scientists did not see the same neurological effects found in pigs exposed to explosions. "We had to ramp up the pressure significantly before we saw [brain-related problems]," says Ling. "That made us step back and say, maybe it's something else, or not the pressure wave alone."

Radovitzky and Moore say that Ling's findings can't be directly compared with their own. Pigs' skulls are thicker than humans', for instance, so the interaction of the pressure wave and the pigs' brains may be different, too. But the apparent contradiction does illustrate just how difficult it is to understand brain injury.

Ling's team will soon begin studying other potential causes of injury, such as electromagnetic pulses (EMPs). If the EMP from a blast is powerful enough, it can interfere with nearby electronic devices. "The brain is an electrical organ," says Ling. "If an EMP pulse can take out a radio, why not short-circuit the brain?"

Meanwhile, the pig studies have shed some light on the biology of blast-related brain injury. Animals subjected to explosions show signs of neurodegeneration: according to Ling, preliminary results suggest that some of the pigs' neural fibers start to break down, triggering cell death primarily in the cerebellum (a brain structure involved in balance and coördination) and the frontal lobes (which play a role in impulse control, judgment, problem solving, complex planning, and motivation). As with the injured soldiers, however, it is not yet clear how the test pigs will fare in the long run—whether they will heal, whether their walking deficits will continue, or whether their initial injuries will set off a spiral of neural degeneration. And perhaps most important, it remains uncertain whether pigs exposed to repeated explosions will suffer exponentially more harm than those whose exposure is more limited.

Ling is overseeing a study of marines being trained to set controlled explosions, which should provide some evidence of the effects of successive but milder blasts. "Because [they] expose themselves repeatedly to blast, we can determine if, in fact, these repeated exposures cause mild TBI," says Ling. The marines will undergo cognitive and neuropsychological testing and intensive brain-imaging studies both before and after their training. And because their blast exposure doesn't occur on the battlefield, they are unlikely to experience the combat stress that can complicate the diagnosis of brain injury.

WWW Watch video interviews with Harvard's Kit Parker and MIT's Raul Radovitzky: **technologyreview.com/iraq.**

MIXED SIGNALS

On May 20, 2004, Jerry Pendergrass's convoy was ambushed. The National Guard sergeant was standing outside his Humvee when a rocket-propelled grenade landed a few feet behind him and exploded, launching him 15 feet in the air. A few moments later, Pendergrass found himself lying on the ground, shrapnel lodged in his leg and his helmet several yards away. He was conscious but unsure of where he was, classic signs of concussion. Another member of his unit pulled him behind the protective barrier of the disabled Humvee, where they awaited evacuation to a medical checkpoint in a secure zone down the road.

Pendergrass soon returned to duty, ignoring the persistent headaches and the sleep, memory, and balance problems that plagued him after the blast. When his tour was up and he returned home to North Carolina, he took prescription painkillers and drank, trying to wash away both his memories of war and the reality of his health problems. It wasn't until he began a second tour—and was evacuated two months later for spinal damage linked to the earlier blast—that he realized the full extent of his injuries. He was diagnosed with both mild traumatic brain injury and post-traumatic stress disorder (PTSD)—a condition, first defined in Vietnam veterans, that can develop after exposure to a terrifying event. "Big bangs scare the living fart out of me," says Pendergrass, in a conference room at the Lakeview Virginia NeuroCare center in Charlottesville, VA. He seems startled by even small noises, jumping as a nearby copy machine is jostled into action.

Pendergrass has spent the last three months at NeuroCare, which is partnered with the Defense and Veterans Brain Injury Center. The small in-patient clinic, with an adjacent residence for patients, offers intensive therapy and is staffed by occupational and physical therapists, speech and language therapists, and clinical psychologists. Pendergrass is getting psychological counseling for PTSD and rehabilitation for his brain injury.

He expects to return home soon, but his recovery is complicated by his dual diagnosis. In blast-injured soldiers, PTSD and mild brain injury often occur together. The two conditions also share symptoms—including depression, memory and attention deficits, sleep problems, and emotional disturbances—and research suggests that they can aggravate each other. A 1998 study of veterans with PTSD found that those exposed to blasts were more likely to have lingering attention deficits and abnormal brain activity that persisted long after the injury. And a study published earlier this year in the *New England Journal of Medicine* found that the 15 percent of soldiers who reported having suffered concussions had a much greater risk of developing PTSD: 44 percent of soldiers who had lost consciousness on the battlefield met criteria for PTSD, compared with 16 percent of those in the same brigades who suffered other injuries.

However, the two conditions can have different prognoses. While PTSD is a serious anxiety disorder, it can often be treated effectively with psychological and drug therapies. Patients with moderate to severe TBI have a far grimmer prognosis. Even people with concussions, who often get better on their own, can have enduring damage: symptoms that linger more than six months may be permanent. No drug treatments have proved effective for curing long-term symptoms, and other therapies are limited. For the most part, patients are simply taught new strategies for dealing with their impairments, such as carrying notepads to help them remember important tasks or designating specific spots for their keys.

Determining the true extent of the Iraq War's brain-injury epidemic will require sorting out whether individual patients' persistent symptoms are caused primarily by PTSD or by physical trauma. Statistical analysis from the *New England Journal of Medicine* study found that lasting symptoms could be attributed largely to PTSD and depression rather than to brain injuries themselves. But the conclusion is controversial. "I think that's minimizing the potential effects of concussion in this equation," says Barth, the University of Virginia neuropsychologist.

The debate over whether the mental wounds of war are biological or psychological has recurred in one form or another in every major war of the last century, ever since powerful explosives became widespread on the battlefield. During World War I, military doctors coined the term "shell shock" to describe the plight of soldiers who stumbled into army hospitals afflicted by dizziness and confusion,

WAGING WAR ON BRAIN INJURY Army neurologist Geoffrey Ling is trying to pinpoint exactly which factors in an explosion damage the brain.

DAVID DEAL

> Ling's team will soon set to work studying specific potential culprits. For example, IED explosions trigger an electromagnetic pulse, which can interfere with nearby electronic devices. "The brain is an electrical organ," says Ling. "If an EMP pulse can take out a radio, why not short-circuit the brain?"

uncontrollable twitching, or an inability to speak. At first, doctors attributed the symptoms to brain damage caused by the frequent explosions that characterized the new trench warfare. But as soldiers who had never been exposed to blasts began reporting similar complaints, military psychiatrists started to suspect a sort of combat-triggered hysteria. A labeling system used by the British army at the time suggests the difficulty of distinguishing between the two problems (and the moral opprobrium attached to those whose condition was deemed psychological). Victims were designated either "shell-shock wounded," meaning the symptoms arose after the soldier was shelled, or "shell-shock sick," meaning the symptoms were not linked directly to an explosion. Only those with "wounded" status were awarded pensions and granted the honor of wearing "wound stripes" on their uniforms.

Walter Reed's David Moore hopes that new imaging technologies will finally resolve the debate by identifying the subtle neurological damage inflicted by concussion. One promising technology is diffusion tensor imaging (DTI), a variation on traditional magnetic resonance imaging (MRI) that highlights white matter, the long nerve fibers connecting brain cells. Recent studies of people with mild traumatic brain injury (from car accidents, for example) suggest that changes in the organization of the brain's white matter correlate with patients' cognitive deficits. Preliminary evidence suggests that patients who show the greatest disruption of white matter early on also have the poorest outcomes.

In a large, ongoing study at Walter Reed, which Moore is overseeing, researchers will use DTI to compare returning soldiers who have experienced blasts and report the hallmarks of concussion—loss of consciousness or situational awareness—with a military control group reporting no previous brain injuries. The scientists hope the images will help them identify specific brain changes linked to concussion, which will make it easier to diagnose the injury and predict its outcome.

OVERWHELMED

Three years after Geoffrey Ling's time in Iraq, his war on brain injury has really just begun. Scientists have preliminary evidence that forces unique to blasts can damage the brain directly, independent of any blunt injuries that the blast might also cause. The key questions, however, remain unanswered. Which aspects of the blast do the most damage? How can the military better protect its personnel? And perhaps most important for legions of soldiers on patrol, can repeated exposure to weak blasts lead to long-lasting brain damage?

The prognosis for soldiers returning home with symptoms of brain damage is not encouraging. Decades of research into civilian head trauma have come to very little; treatments that seemed promising in animal models have turned out to be ineffective in human tests. "It's a completely untapped area of medical development," says trauma surgeon Jon Bowersox. While the military is testing a handful of existing drugs, there's a "time mismatch" when it comes to developing new treatments specifically for traumatic brain injury, Bowersox observes. "The military is interested in developing products they can have out during the current war," he says. "They are not used to the fact that medical development has a longer time line."

Even the few therapies that do exist will be difficult to deliver to everyone who needs them. "What will we do with all these people?" asks Barth. "We're talking about thousands. This is going to overwhelm the VA hospitals." The military is preparing some of those hospitals to better deal with brain injury, hiring neuropsychologists to make diagnoses and other experts to run rehabilitation programs. But resources are limited. At some of the medical centers, "physicians haven't had any training in rehabilitation other than clinical medicine," says Bowersox.

Perhaps the greatest challenge will be to help injured soldiers resume their previous lives. "Young people are not equipped emotionally and financially to handle this," says Marilyn Price Spivack, founder of the Brain Injury Association of Massachusetts, which has recently begun an outreach effort aimed at veterans. "Often they can't go back to their civilian jobs and are very hard to employ."

The goal of facilities like NeuroCare is to return people to service or to their civilian jobs. But even a quick visit with some of the patients shows what a long road that will be for many of them. In the clinic, one patient apologizes as he twitches uncontrollably. Another abruptly leaves the room, suddenly overcome with anxiety. And Pendergrass, who has had serious balance problems since he was injured, is unlikely to be able to return to his previous job hanging power lines. He doesn't yet know what he'll do when he leaves the rehab center. TR

EMILY SINGER IS *TR*'S BIOTECHNOLOGY AND LIFE SCIENCES EDITOR.

Una Laptop por Niño

THE PHILANTHROPIC PROJECT FIRST KNOWN AS THE "$100 LAPTOP" HAS FALLEN FAR SHORT OF GRAND INITIAL GOALS. BUT IN PERU, 486,500 MACHINES ARE HEADED FOR SOME OF THE WORLD'S POOREST AND WORST-EDUCATED CHILDREN.

By DAVID TALBOT

A fleeting roadside scene in Lima, Peru, sticks in my mind. A very little girl, perhaps four, stood on a narrow traffic island bisecting a congested thoroughfare amid choking dust, soot, and fumes. With the girl was a woman I took to be her mother. The mother, a street peddler, was unpacking a crate full of something. (I couldn't see what, but other peddlers offered avocados, toilet paper, and toy rats.) Around them roared 1970s-era buses and battered vehicles, passing below concrete habitations creeping up dismal, denuded hillsides in one of the city's vast slums. The child was energetically scooping up plastic bags for her mother, her shaggy brown hair flopping forward. Not far away, an old woman picked through a pile of smoldering refuse. Against the squalid tableau, the girl was tidying her little corner of Lima as she spent her morning helping Mom at work.

Photographs by ANA CECILIA GONZALES-VIGIL/WPN

EARLY ADOPTERS Children carry XOs at the Institución Educativa Apóstol Santiago in Arahuay, Peru, where almost 50 kids have being using prototype laptops since last summer. They are at the vanguard of the world's largest deployment of OLPC computers—to Peru's most remote primary schools.

I thought of her as I passed through steel gates manned by armed guards at Peru's Ministry of Education to talk to Oscar Becerra, general director for educational technologies. Peru is poised to deliver 486,500 laptops to its poorest children under the One Laptop per Child program—a figure that could swell to 676,500 if the Cuzco region buys in. It is the largest such OLPC purchase in the world *(see "OLPC Scales Back," p. 64)*. I asked Becerra whether children in Lima's slums would receive the green-and-white machines. "No," he said. "They are not poor enough." At first I thought he was making a hard-hearted joke. But he went on to explain that Lima residents generally have electricity and (in theory) access to city services, even Internet cafés. The laptops are headed to 9,000 tiny schools in remote regions such as Huancavelica, in the Andes, an arduous 12-hour bus ride over rocky roads southeast of Lima, and villages such as Tutumberos, in the Amazon region, days away. By the standards of children in those areas, the girl on the traffic island enjoyed enviable opportunity.

What Becerra told me drove home the true scope of what OLPC is trying to do in a country that, according to a survey by the World Economic Forum, ranks 130th out of 131 countries in math and science education, and 131st in the quality of its primary schools. "There is a long-term social cleavage in Peru that has been around forever," says Henry Dietz, a political scientist and expert on Peru at

With the laptops, says a government official, "we are reaching the poorest schools in Peru for the first time." The effort is also "critical to the future of OLPC," says the organization's founder.

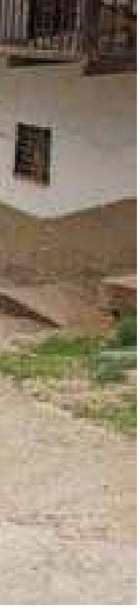
the University of Texas at Austin, describing the country's income inequality and rural poverty. "You get out of those provincial capitals, a half-hour in any direction, and you are in rural Peru, and things are pretty primitive. Electricity is a sometimes thing, and the quality of education—the school is four walls and a roof and some benches, and that is about it. There is very little there to work with." In some cases, the laptop deployment will tie in to an existing program to bring Internet access to certain schools. But for the most part, the machines are entering an educational vacuum.

And they're bringing with them a whole new pedagogy. The computers come loaded with 115 books—literature such as *Mi Vaquita*, about a rare porpoise, but also classics, like some of Aesop's fables, novels (at least one by the Peruvian writer Mario Vargas Llosa), and poetry (including verse by the early-20th-century Peruvian poet César Vallejo). The laptops' flash drives also store introductions for teachers, reading-comprehension programs and other educational software, a word processor, art and music programs, and games, including chess, Sudoku, and Tetris. The rugged, low-power hardware includes a camera that can capture video or still images. The computers are Internet ready and can wirelessly relay data to one another.

These tools will land in the hands of first through sixth graders who in many cases never even had books—at home or elsewhere—and whose teachers themselves had little education. They will not come cheap; Peru is spending about $80 million on the laptops—nearly a third of the education budget normally available for capital expenditures—plus about $2 million for teacher training. Becerra characterized the sum as a special appropriation meant to bring schools up to date. "To distribute all these books would cost five times the cost of the machines," he estimates. "We are reaching the poorest schools in Peru for the first time in history." The hope is that more children will make lives for themselves beyond subsistence farming or menial labor.

Peru's move comes at a critical time for OLPC, because the nonprofit has failed to achieve the manufacturing scale and low prices it initially sought *(see "Philanthropy's New Prototype," November/December 2006 and at TechnologyReview.com)*. One Laptop per Child was unveiled in early 2005 at the World Economic Forum in Davos, Switzerland, by Nicholas Negroponte, the cofounder and chairman emeritus of MIT's Media Lab. "We will not launch this without five to ten million units in the first run," Negroponte said at the Technology, Entertainment, Design (TED) conference in February 2006. He set goals of building seven million to ten million machines in 2007 and 100 million to 200 million in 2008, listing seven major countries as potential early customers: China, India, Thailand, Egypt, Nigeria, Brazil, and Argentina. "If it comes out at $138, so what?" he said at TED, predicting that mass production would drive the price down. "If it comes out six months late, so what? That's a pretty soft landing."

OLPC's actual landing was far bumpier. Yes, the production computer, called the XO, is cheaper, sturdier, and less power hungry than any laptop previously made: it uses just two to five watts, peaking at nine watts, about a 10th the power consumption of a typical laptop. Its battery is long lasting, cheap to replace, and relatively easy on the environment. But the laptops wound up costing not $100, or $138, but $188 each. Large countries have been slow to buy; the harshest reaction came in 2006 from the Indian education secretary, Sudeep Banerjee, who dismissed the program as "pedagogically suspect" and declared, "We need classrooms and teachers more urgently than fancy tools." Competitors arose; Intel's Classmate PC, while not as rugged, did tempt some potential customers. A partnership between OLPC and Intel, forged in 2007 to



LIFE WITH LAPTOP Nine-year-old Nilton Quispicóndor (standing, far left) uses his computer at school in Arahuay, Peru. Later he totes it up the village stairs (center) before setting up shop in his house (right), as his father, Huber, a farmer, looks on.

find collaborations between their existing educational and technological efforts, ended bitterly six months later. The first OLPC customers have turned out to be Peru and Uruguay, with smaller initiatives in Mongolia and—in a surprise nobody imagined—Birmingham, AL. (And rather than being paid for by governments, some of these efforts were funded by donations made through OLPC's Give One, Get One program.) Altogether, the first group of customers has ordered only about 500,000 machines, a figure that includes some, but not all, of Peru's planned acquisition.

If Peru's effort succeeds, however, it will become a model for other nations. Peru launched its teacher education program in late winter, and curricula are being designed that can be delivered to the laptops and updated over the Internet. By providing low-cost access to books, lessons, games, and activities, the machines are meant to help realize a so-called constructionist model of education, in which kids learn largely by exploring, discovering, and collaborating. "It is so important, because [Peru] is doing everything right," Negroponte told me in his small office near the MIT campus, with a view of the Boston skyline. "They are doing remote schools, they are doing it with constructionism, they are doing it at scale. The only thing they have going against them, if you will, is that they are first, and we will be debugging things as we go. But it is absolutely critical to the future of OLPC." When I visited Peru in mid-March, distribution of the laptops had not yet begun. But a clue to how the effort might fare can be found in a Peruvian mountain farming village where, last year, prototypes were handed out to kids in a trial run.

A GOAT CALLED PALOMA

The first hour of the drive from central Lima is a tour of sprawl and poverty. Then comes 90 minutes in which the traffic thins and the scenery gives way to vegetable farms in the valleys of the Andean foothills. The air clears and cools as the elevation passes 1,000 meters and you traverse the small town of Santa Rosa de Quives. You turn off onto a desolate, rocky dirt road and continue for another hour. The road switches and jogs its way to 2,600 meters, skirting perilous precipices. Finally, rounding a bend, you glimpse the corrugated-steel roofs of Arahuay, an agricultural village of 742 residents. The steep surrounding hills contain pre-Inca archaeological sites and sparkling cold ponds. In the town's colonial-era church is a Virgin Mary statue festooned with plastic flowers.

Arahuay is poor, but as Becerra explained later, it is also "not poor enough" to warrant laptops under the national rollout. Nevertheless, it was here that the Ministry of Education decided to test a preproduction model of the OLPC machines. Arahuay is relatively handy to Lima (battered buses make two trips daily), and it has a preëxisting Internet connection (a satellite dish was installed as part of the earlier Peruvian initiative). The laptops arrived in June 2007 and were delivered to the first building you encounter in Arahuay: the Institución Educativa Apóstol Santiago, a clean-swept, U-shaped concrete-block school with a concrete yard and corrugated-steel roofing, open at the eaves. The primary school has 46 students: 8 in the first and second grades, 21 in the third and fourth grades, and 17 in the fifth and sixth grades. (The town also has a secondary school, but many children drop out by then.) Some of Arahuay's students come from smaller hamlets in the region that lack schools of their own. These children travel (often by foot) to Arahuay on Sunday night and leave on Friday; during the week they sleep in a bunkhouse owned by the town and run by a Catholic charity, where they are fed hearty meals, such as a spicy (and tasty) potato-based stew ladled out by a cheerful house mother.

The teachers knew we were coming. The children were at their desks, pecking away at their now-battered laptops. The machines were clearly well worn, with names written in marker to distinguish them (OLPC has since added color coding on the logo's X and O, with 400 combinations, so kids can tell them apart). It was Monday, March 10, which happened to be the first day of school in Arahuay after the Peruvian summer. Kevin Gabino, 11, was following a teacher's instructions to type a statement of the school's values into a text file (*Llegar temprano al colegio*—Be early to school—topped the list). Several other kids were playing Tetris. Rosario Carrillo, 10, was performing a Google search for "*elemento de la comunicación*," but the town's Internet connection was so slow that the wait dragged into minutes. Rosario said she uses the laptop to

OLPC SCALES BACK

One Laptop per Child initially hoped to manufacture millions of machines for a few large countries. But most of the orders that have come in so far are relatively small. Here is where OLPC's efforts stand, according to its founder, Nicholas Negroponte.

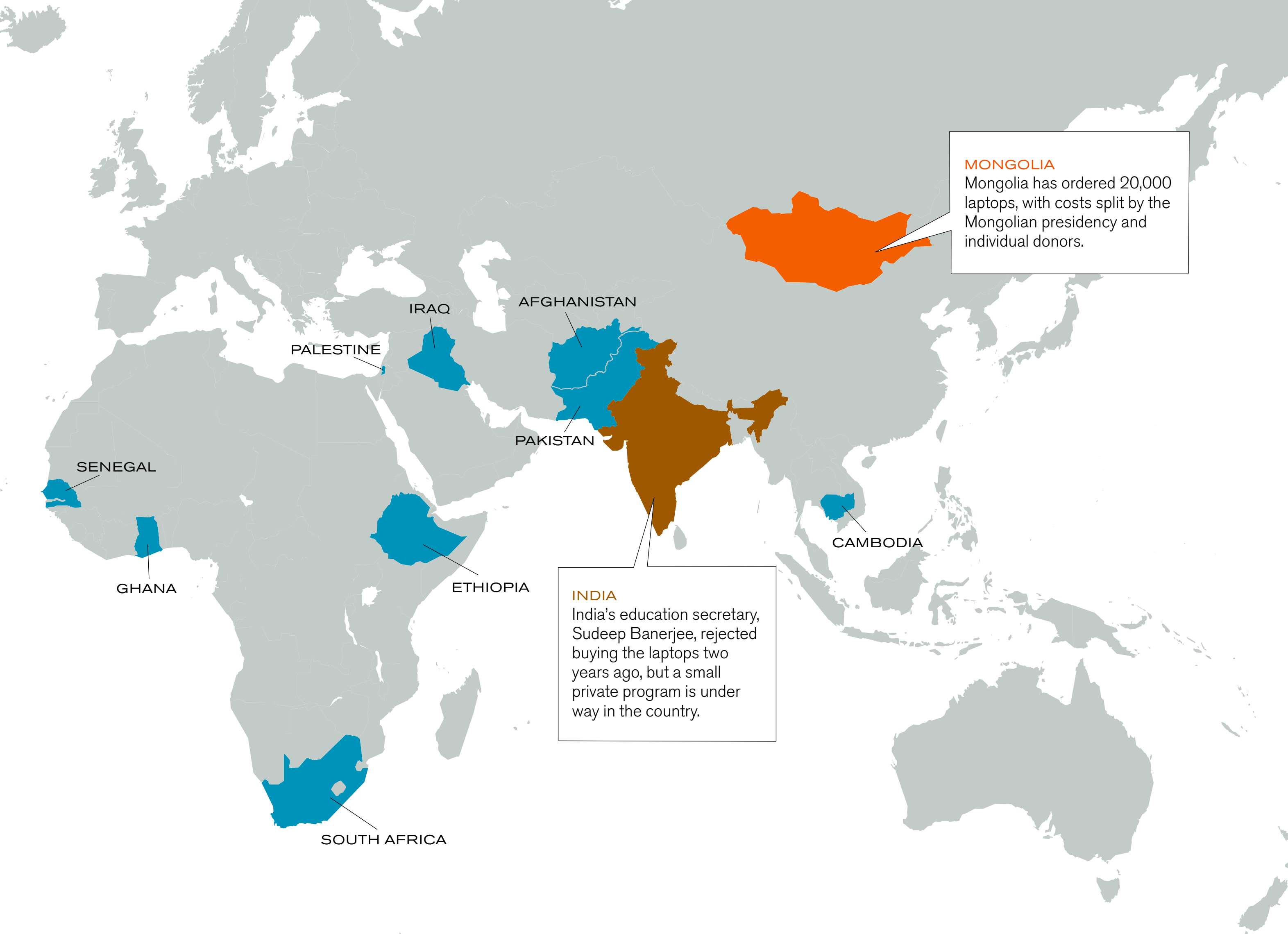
play games, take pictures, draw, perform calculations, write documents, and send e-mails to her 25-year-old sister, who works in Lima "washing clothes and looking after babies."

Cecilia Aquino, also 10, clutched hands with Rosario. She chimed in that she has used her laptop's video camera to make grainy movies of her father's goat, which she named Paloma. Becerra told me that such pursuits were part of the plan. "One of the problems with education worldwide is that children don't understand why they should learn what they are supposed to learn," he says. "When you have a computer, and students own the computer, they begin finding 'why.' They realize they can actually do something that is meaningful to them. For example, if they want to make a movie about their crops or their animals, they need to learn all the related aspects—not only technology, but expression, articulation, artistic representation."

Of course, the kids use the computers for more standard educational pursuits as well. The school's principal, Patricia Peña Cornejo, said that assignments often require students to search the Web for basic information, such as facts about local flora and fauna. "I am happy because I see how the children learn," she said. "The communication between the students is better. They talk to each other about things they saw on the Internet." Students are directed to educational Web pages; some other sites have been blocked by the ministry, Cornejo said. But one of the biggest benefits she sees is the possibility of access to instructional materials and digital books. (The Arahuay computers didn't come loaded with books, but some were apparently downloaded later.) "The people are very poor here and don't have many books," added one teacher, Judith Inocente Olórtequi. "Not all kids can buy books."

I asked nine-year-old Nilton Quispicóndor whether he liked his laptop. "*Sí!*" he replied enthusiastically, as he toted the computer home from school. The concrete house he lives in is dark and roofed with corrugated steel; it has no electricity, but the laptops can be charged at school, and a charge lasts four to eight hours. Sacks of potatoes sat in the cluttered kitchen. Asked about his typical after-school routine, Nilton replied, "First I have lunch, then I change my clothes, then I play with my laptop." He opened up Tetris and played a round. Then he opened the drawing program and drew a picture of a house with a pitched roof, a door, and win-

WWW | *TR*'s chief correspondent, David Talbot, visits Arahuay, Peru, site of an early OLPC deployment: **technologyreview.com/olpc**.



dows. Last, he opened a digital copy of "*Las Habichuelas Mágicas*," the Spanish-language version of "Jack and the Beanstalk"—a story that Becerra later said must have been downloaded by a teacher. The boy's father, Huber Quispicóndor, a 48-year-old who tends a *chacra* (small farm) of potatoes and corn, watched with pride. "He knows how to use the computer—he knows how to use every part of it," Huber said in uneven Spanish (he speaks Quechua, an indigenous language). "Above all, it is more knowledge for him."

I asked whether the machines had broken down or been misused, but I heard no horror stories. True, teachers and administrators may have been wary of criticizing a ministry effort, and for my part, I faced a language barrier. But my impressions were of a proud and supportive father, effusive teachers, and kids making creative use of their laptops. I asked Becerra what Peru wanted for children like Nilton. "Our hope for him is that he will have hope," he said. "So we are giving them the chance to look for a different future—or the same, but by choice, not by force. These children who didn't have any expectation about life, other than to become farmers, now can think about being engineers, designing computers, being teachers—as any other child should, worldwide." The challenge, Becerra said, "is how to transmit a technology and a knowledge that people in the poor areas never saw, and never heard of."

OPPORTUNITIES AND DISASTERS

And by all accounts, that challenge dwarfs those associated with designing the laptop in the first place. Fernando Reimers, director of global education at the Harvard Graduate School of Education, recalls a scene he witnessed in Peru during an earlier effort to put PCs in certain schools. Visiting a school in the town of Trujillo, Reimers found that the computers were kept in one room. The teachers were so concerned about dust, which they understood could damage the machines, that they kept the windows closed and the door locked, and frequently polished the floor with a petroleum-based cleaner. The result: a suffocating, smelly shrine to unused technology. "I am very positive on the potential of innovation to make things happen," Reimers says. "I also know that in education, when it comes to large-scale reform, the devil is in the implementation. Sometimes implementations can take great opportunities and turn them into disasters."

LAPTOP LAUNCH In a Lima warehouse, 25,000 OLPC machines are inventoried and loaded with updated software. Boxes containing five laptops apiece are stacked on individual pallets, labeled by village and school.

Reimers pointed out that Peru faces no small challenge in ensuring that the machines get where they're supposed to go (and aren't stolen once there), and in seeing that thousands of teachers learn how to use them, keep them maintained, and share successful experiences with each other. But while Reimers and other educators were apprehensive about Peru's capacity to sustain the program in far-flung locations, they also saw undeniable potential. "The schools really urgently need something that can bring information from outside, and it's not likely to be a library of books," says Marcia Koth de Paredes, who spent 26 years as executive director of the Fulbright Scholar Program in Peru. If the children tap the laptops' content, she says, the machines can only be a positive force.

In Lima, I visited an olive-green warehouse, a 25-minute drive from the education ministry. Boxes containing five XOs apiece—25,000 in all—were stacked in neat columns. Young men were unpacking the boxes, installing batteries in the laptops, and affixing bar-code stickers to them. At another table, a worker used a thumb drive to load updated software onto the machines, five at a time, before sheathing them in plastic and returning them to the boxes. The finished boxes were organized on pallets labeled by region, village, and school. To protect against theft, the computers leave the factory digitally locked; only when they arrive at their destinations (or as close as is practically possible) will teachers receive USB drives containing the codes to unlock them.

Delivery might be easy compared with the monumental task of turning ill-educated teachers, generally unfamiliar with computers, into OLPC experts in 9,000 schools. There will be much to learn: how to operate, maintain, and recharge the laptops, and how to take advantage of all the digitized texts and software. Most of the villages have intermittent electricity, and those without it will get generators or photovoltaic recharging systems. But 90 percent of the villages also lack Internet connections; the nearest access points are at regional education offices. Teachers will be shown how to upload updated content to the laptops; in theory, when they make their monthly trips to the regional offices to pick up their paychecks, they will be able to download new material onto thumb drives, then install it on the laptops. "Peru is being very ambitious in reaching out to the most-needy kids right from the get-go, but it introduces some logistical challenges," says Walter Bender, OLPC's director of deployment *(see Q&A, March/April 2008 and at TechnologyReview.com)*, who traveled to Peru in February and March. When I interviewed him in late March, he was writing a deployment manual that can be generalized to later-adopting countries. They "didn't have such a document" for Peru, he said, "so there was lot more hand-holding and discovery that had to happen."

It's not hard to imagine glitches and misunderstandings emerging from all this. But in the end, the verdict on OLPC in Peru will come from the children. Until now, many of them have had a limited sense of their own potential, says Lawrence E. Harrison, a Latin America expert and director of the Cultural Change Institute at Tufts University's Fletcher School of Law and Diplomacy. "You have to put yourself in the shoes of the kid, and the eyes of the kid, and it's not easy to do," Harrison says. "The vast majority of these kids grow up with images of programs from TV but are convinced that this goes on in another part of the world that doesn't affect them. They have a fatalistic worldview, often reinforced by religion. They do not connect education with their own progress. They see it as something that has to be done. So really, the success of this should not be measured in terms of their ability to manipulate the instrument, but in changing the way they see their prospects."

That's why Harrison and Reimers think that programs to evaluate children before and after they work with the computers—something Becerra says is planned—must measure values and attitudes as well as math skills and literacy. Are the kids focused on the future? Do they believe that knowledge matters? Do they associate work with the possibility of getting ahead, or just with survival? "Based on all the panaceas that we have experienced since the 1950s, I start with a little bit of skepticism" about the OLPC deployment in Peru, Harrison says. "But certainly, if I had been in the position of deciding whether to do it or not, I would have tried it."

The success of OLPC can no longer be judged against Negroponte's early predictions and plans, nor by the technical merits of the laptop itself. Peru is what matters now. When I was in Lima, OLPC's former chief technology officer, Mary Lou Jepsen (she has formed Pixel Qi, a startup dedicated to making even lower-cost displays for OLPC's computers and others), visited the education ministry to offer help and show staffers how to repair the machines. But she acknowledged that OLPC's future doesn't revolve around the hardware she helped bring about. "Laptops are easy; education is hard to transform," she said. "I don't even speak Spanish. How can I even start to transform primary education in Peru?"

In truth, she can't. But Peru now has a chance to help Rosario, Cecilia, Nilton, and 486,497 other kids—and, maybe, someday, the little girl on the traffic island in Lima. TR

DAVID TALBOT IS *TECHNOLOGY REVIEW*'S CHIEF CORRESPONDENT.

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An Electrifying Startup

By KEVIN BULLIS

WITH A NEW BATTERY FROM A123 SYSTEMS, ELECTRIC CARS COULD COME TO DOMINATE THE ROADS.

It is the quickest electric motorcycle in the world. On a popular YouTube video, the black dragster cycle nearly disappears in a cloud of smoke as the driver does a "burn-out," spinning the back wheel to heat it up. As the smoke drifts away, the driver settles into position and hits a switch, and the bike surges forward, accelerating to 60 miles per hour in less than a second. Seven seconds later it crosses the quarter-mile mark at 168 miles per hour—quick enough to compete with gas-powered dragsters.

What powers the "Killacycle" is a novel lithium-ion battery developed by A123 Systems, a startup in Watertown, MA—one of a handful of companies working on similar technology. The company's batteries store more than twice as much energy as nickel-metal hydride batteries, the type used in today's hybrid cars, while delivering the bursts of power necessary for high performance. A radically modified version of the lithium-ion batteries used in portable electronics, the technology could jump-start the long-sputtering electric-vehicle market, which today represents a tiny fraction of 1 percent of vehicle sales in the United States. A123's batteries in particular have attracted the interest of General Motors, which is testing them as a way to power the Volt, an electric car with a gasoline generator; the vehicle is expected to go into mass production as early as 2010.

In the past, automakers have blamed electric vehicles' poor sales on their lead-acid or nickel-metal hydride batteries, which were so heavy that they limited the vehicles' range and so bulky that they took up trunk space. While conventional lithium-ion batteries are much lighter and more compact, they're not cost effective for electric vehicles. That's partly because they use lithium cobalt oxide electrodes, which can be unstable: batteries based on them wear out after a couple of years and can burst into flame if punctured, crushed, overcharged, or overheated. Some automakers have tried to engineer their way around these problems, but the results have been expensive.

A123's batteries could finally make lithium-ion technology practical for the auto industry. Instead of cobalt oxide, they use an electrode material made from nanoparticles of lithium iron phosphate modified with trace metals. The resulting batteries are unlikely to catch fire, even if crushed in an accident. They are also much hardier than conventional lithium-ion batteries: A123 predicts that they will last longer than the typical lifetime of a car.

The battery's promise has made A123 one of the best-funded technology startups in the country, with $148 million in venture capital investments so far. With the funding, A123 has been pursuing an ambitious business plan that calls for it to do everything from perfecting the material to manufacturing batteries and selling them to customers in the auto and power-tool industries.

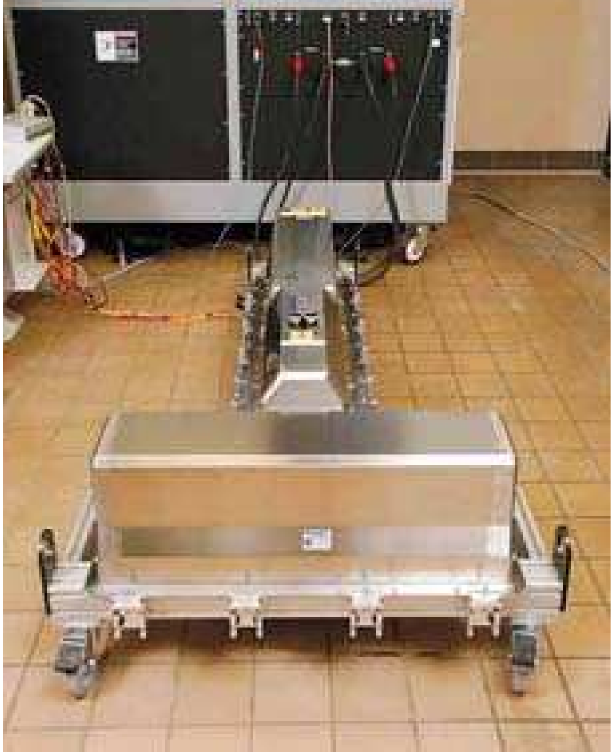
The A123 batteries for GM's Volt store enough energy for 40 miles of driving, enough to cover daily commutes. (On longer trips, the small gasoline engine would kick in to recharge the battery, extending the range to more than 400 miles.) GM plans to sell the vehicles for around $30,000 to $35,000; the company thinks it can sell hundreds of thousands at that price in the first several years, and J. D. Power and Associates estimates that GM will sell nearly 300,000 by 2014.

MATERIALS MATTER

In early 2001, a 26-year-old Venezuelan entrepreneur named Ric Fulop walked into the office of Yet-Ming Chiang, a professor of materials science at MIT, without an appointment. "He just showed up and knocked on the door," recalls Chiang. Fulop, who had already founded three venture-backed companies, wanted help starting a battery company, and he knew that Chiang was conducting battery research involving nanotechnology. Chiang himself had cofounded a successful startup in the late 1980s, but he spent most of his time researching nanotechnology and the chemistry of advanced ceramics.

PORTER GIFFORD

SIDE IMPACT A battery designed by A123 Systems for GM's Volt electric vehicle can survive a crushing safety test. The high-velocity impact could have caused other lithium-ion batteries to overheat and catch fire.



PACKED UP A123's battery cells (right) have been integrated into a T-shaped pack engineered by the German firm Continental (above). GM is testing the pack under simulated driving conditions before bolting it into an electric-vehicle prototype.

COURTESY OF GENERAL MOTORS

By the fall, Fulop and Chiang, along with Bart Riley, an engineer Chiang knew from his previous venture, had cofounded A123 Systems. The plan was to commercialize one of Chiang's more radical ideas: materials that, when stirred together, would spontaneously assemble to form a working battery. The process promised to multiply energy storage capacity while lowering manufacturing costs.

Chiang's big idea turned out to be a hit with investors. By the end of 2001, a first round of funding had brought in $8.3 million from various venture capital firms. Motorola and Qualcomm, intrigued by the prospect of better batteries for portable electronics, soon added $4 million. But it quickly became clear that a commercial self-assembling battery was years away from reality. The technology "was still pretty rudimentary," Chiang says.

In early 2002, however, Chiang made a surprising discovery that would completely change the company's direction. He had begun to work with lithium iron phosphate, which is nontoxic, safe, and inexpensive, unlike the materials used in other lithium-ion batteries. But it appeared to have some serious drawbacks. It stores less energy than lithium cobalt oxide, the electrode material in conventional lithium-ion batteries, so it seemed unsuitable for use in portable electronics, where energy storage is paramount. Also, it charges and discharges slowly, ruling out its use in high-power applications such as hybrid electric vehicles; even for fully electric cars, which use many more battery cells than hybrids, the material couldn't deliver enough power.

So Chiang started to modify it by adding trace amounts of metals. Soon the material was discharging power at relatively high rates. In mid-2002, he flew to Monterey, CA, to present his findings at a conference. While he was there, a graduate student back at MIT continued running tests. By the time Chiang was scheduled to talk, the material was performing at rates four times those he had come to announce. "At that point, we knew we had something special," he says.

Eventually, Chiang would demonstrate that the material could deliver bursts of electricity at 10 times the rate of those used in conventional lithium-ion batteries. After studying the high-performing material in detail, he determined that it owed its power both to the size of the particles he'd used (less than 100 nanometers) and to the addition of the extra metals. The combination of those factors, he says, causes a fundamental difference in the way the atoms that make up the material rearrange themselves when they receive and release a charge.

In all lithium-ion batteries, electricity is generated when lithium ions shuttle between two electrodes while electrons travel through an external circuit. In Chiang's early experiments with lithium iron phosphate, the parts of the material that contained lithium would separate from those that didn't as the lithium ions moved in and out of an electrode. That changed the crystalline structure of the material, and its performance deteriorated. But, Chiang discovered, when the particles of lithium iron phosphate are small enough—and the electrode has been modified, or "doped," through the addition of other metals—the material's crystalline structure changes far less. As a result, the lithium ions can move in and out faster, without degrading the material. Altogether, Chiang found that the modified material charged and discharged faster than ordinary lithium iron phosphate, and it lasted longer, too.

Extraordinary though the new battery material seemed to be, Chiang realized immediately that it wasn't ideal for portable electronics. There didn't seem to be a ready market for light, compact batteries that delivered large bursts of power. Hybrid vehicles, a natural fit, were only beginning to appear on the market. What Chiang didn't know was that a major power-tool company was working quietly on a new generation of cordless tools, and it was having trouble finding a battery that would meet its needs.

WWW See how an electric car recharges itself, and hear how the originator of A123's technology is going to change the automotive industry: **technologyreview.com/A123**.

POWERFUL START

In 2003, representatives of Black and Decker met with Fulop and A123's CEO, Dave Vieau, and told them that they wanted to make cordless power tools that would perform better than tools plugged in to the wall. A123's material seemed like a perfect fit. In short bursts, it can deliver more power than a household circuit. And it had other features that would be attractive on a construction site. It could be recharged quickly (to 80 percent of capacity in 12 min-

utes or less), and unlike batteries made with lithium cobalt oxide, it could survive harsh treatment without catching fire.

That, at least, was the theory. When Fulop and Vieau first met with Black and Decker, they had only a model of a battery cell, half a gram of material, and a PowerPoint presentation. What Black and Decker needed was a company that could produce millions of batteries. "There was a lot of emphasis on the material, but what we had to learn how to do is to engineer the complete cell," Chiang says.

Within a year of signing its initial agreement with Black and Decker, however, A123 had produced a commercially feasible battery. By November 2005, its first products were coming off assembly lines in Asia. In less than three years, the company went from building a demonstration battery the size of a coin to building 50-meter-long coating machines and 28,000-square-meter factories run by hundreds of employees. By 2006, customers were buying its batteries in a new line of professional tools sold by Black and Decker. In short order, A123 was manufacturing batteries at the rate of millions a year.

CHARGING UP CARS

Meanwhile, GM was rethinking its technology strategy as Toyota began to dominate the hybrid-vehicle business. A hybrid uses a battery only part of the time, relying on a gasoline engine for much of its power. GM decided to develop a car that would allow its customers to stop using gasoline entirely for most daily driving. But to pull it off, the automaker needed a high-performance, reliable battery. And for that it turned to A123.

PORTER GIFFORD

GM knew that it wanted to use lithium-ion batteries because of their storage capacity, says Denise Gray, GM's director of energy storage systems. But it also knew that existing technology wouldn't do the trick. Though a lithium-ion laptop battery might survive 500 complete charge-and-discharge cycles before its capacity fades, no car owner wants to buy a new battery every 18 months. According to A123's projections, however, its batteries should be able to deliver more than 15 years' worth of daily charges. And in addition to being safer than other lithium-ion batteries, A123's operate at a lower temperature, which makes it simpler to pack hundreds of them together into a large battery pack, Gray says.

Where A123's power-tool batteries are cylindrical, the battery it developed for the Volt is flat, to save space and more efficiently dissipate heat. The cells have been assembled into complete battery packs, which are T-shaped and nearly two meters long. This spring, the batteries will be bolted into vehicle prototypes for road testing. And later this year, A123 plans to increase production of the batteries to meet anticipated demand. The first cars powered by A123 technology could be rolling off assembly lines in 2010. (GM is also testing batteries from another company, and may use batteries from either or both companies.)

If the Volt is popular, electric cars could finally start to take off—and that could reduce greenhouse-gas emissions and petroleum consumption. A recent study by the Electric Power Research Institute and the Natural Resources Defense Council suggests that electric vehicles similar to GM's car could eliminate billions of tons of greenhouse-gas emissions between 2010 and 2050. A study by General Electric indicates that if half the vehicles on the road in 2030 are electric-powered, petroleum consumption in the United States will shrink by six million barrels a day.

And batteries like A123's could have repercussions far beyond the Volt. Even cars with internal-combustion engines are being engineered to rely more on electricity: the simplest examples involve batteries recharged by souped-up alternators that would allow a car to shut off its engine when it approaches a stoplight and restart when the driver hits the accelerator. In conventional hybrids, versions of A123's batteries can deliver as much power as nickel-metal hydride batteries at one-fifth the weight. The new batteries could also benefit plug-in hybrids, which can be recharged from a standard electrical outlet. Indeed, A123's batteries may be used in a plug-in version of the Saturn Vue hybrid SUV that's due out in 2010.

Whatever their design, future cars will be likely to rely much more on electricity. "We're not there yet," Chiang says. "There aren't Volts all over the place. But the potential to have a big impact, both on the oil supply issue and greenhouse gases—I didn't imagine that we'd be able to do that. Certainly not when I started working on batteries." TR

KEVIN BULLIS IS *TR*'S NANOTECHNOLOGY AND MATERIALS SCIENCE EDITOR.

Where Are They?

WHY I HOPE THE SEARCH FOR EXTRA-TERRESTRIAL LIFE FINDS NOTHING.

By NICK BOSTROM

People got very excited in 2004 when NASA's rover *Opportunity* discovered evidence that Mars had once been wet. Where there is water, there may be life. After more than 40 years of human exploration, culminating in the ongoing Mars Exploration Rover mission, scientists are planning still more missions to study the planet. The *Phoenix*, an interagency scientific probe led by the Lunar and Planetary Laboratory at the University of Arizona, is scheduled to land in late May on Mars's frigid northern arctic, where it will search for soils and ice that might be suitable for microbial life *(see "Mission to Mars," November/December 2007, and at TechnologyReview.com)*. The next decade might see a Mars Sample Return mission, which would use robotic systems to collect samples of Martian rocks, soils, and atmosphere and return them to Earth. We could then analyze the samples to see if they contain any traces of life, whether extinct or still active.

Such a discovery would be of tremendous scientific significance. What could be more fascinating than discovering life that had evolved entirely independently of life here on Earth? Many people would also find it heartening to learn that we are not entirely alone in this vast, cold cosmos.

But I hope that our Mars probes discover nothing. It would be good news if we find Mars to be sterile. Dead rocks and lifeless sands would lift my spirit.

Conversely, if we discovered traces of some simple, extinct life-form—some bacteria, some algae—it would be bad news. If we found fossils of something more advanced, perhaps something that looked like the remnants of a trilobite or even the skeleton of a small mammal, it would be *very* bad news. The more complex the life-form we found, the more depressing the news would be. I would find it interesting, certainly—but a bad omen for the future of the human race.

How do I arrive at this conclusion? I begin by reflecting on a well-known fact. UFO spotters, Raëlian cultists, and self-certified alien abductees notwithstanding, humans have, to date, seen no sign of any extraterrestrial civilization. We have not received any visitors from space, nor have our radio telescopes detected any signals transmitted by any extraterrestrial civilization. The Search for Extra-Terrestrial Intelligence (SETI) has been going for nearly half a century, employing increasingly powerful telescopes and data-mining techniques; so far, it has consistently corroborated the null hypothesis. As best we have been able to determine, the night sky is empty and silent. The question "Where are they?" is thus at least as pertinent today as it was when the physicist Enrico Fermi first posed it during a lunch discussion with some of his colleagues at the Los Alamos National Laboratory back in 1950.

Here is another fact: the observable universe contains on the order of 100 billion galaxies, and there are on the order of 100 billion stars in our galaxy alone. In the last couple of decades, we have learned that many of these stars have planets circling them; several hundred such "exoplanets" have been discovered to date. Most of these are gigantic, since it is very difficult to detect smaller exoplanets using current methods. (In most cases, the planets cannot be directly observed. Their existence is inferred from their gravitational influence on their parent suns, which wobble slightly when pulled toward large orbiting planets, or from slight fluctuations in luminosity when the planets partially eclipse their suns.) We have every reason to believe that the observable universe contains vast numbers of solar systems, including many with planets that are Earth-like, at least in the sense of having masses and temperatures similar to those of our own orb. We also know that many of these solar systems are older than ours.

From these two facts it follows that the evolutionary path to life-forms capable of space colonization leads through a "Great Filter," which can be thought of as a probability barrier. (I borrow this term from Robin Hanson, an economist at George Mason University.) The filter consists of one or more evolutionary transitions or steps that must be traversed

STAR CLUSTERS, AS VIEWED THROUGH THE HUBBLE TELESCOPE
Although there are about 100 billion stars in our galaxy, and 100 billion galaxies in the observable universe, the human race seems to be alone.

at great odds in order for an Earth-like planet to produce a civilization capable of exploring distant solar systems. You start with billions and billions of potential germination points for life, and you end up with a sum total of zero extraterrestrial civilizations that we can observe. The Great Filter must therefore be sufficiently powerful—which is to say, passing the critical points must be sufficiently improbable—that even with many billions of rolls of the dice, one ends up with nothing: no aliens, no spacecraft, no signals. At least, none that we can detect in our neck of the woods.

Now, just where might this Great Filter be located? There are two possibilities: It might be behind us, somewhere in our distant past. Or it might be ahead of us, somewhere in the decades, centuries, or millennia to come. Let us ponder these possibilities in turn.

If the filter is in our past, there must be some extremely improbable step in the sequence of events whereby an Earth-like planet gives rise to an intelligent species comparable in its technological sophistication to our contemporary human civilization. Some people seem to take the evolution of intelligent life on Earth for granted: a lengthy process, yes; complicated, sure; yet ultimately inevitable, or nearly so. But this view might well be completely mistaken. There is, at any rate, hardly any evidence to support it. Evolutionary biology, at the moment, does not enable us to calculate from first principles how probable or improbable the emergence of intelligent life on Earth was. Moreover, if we look back at our evolutionary history, we can identify a number of transitions any one of which could plausibly be the Great Filter.

For example, perhaps it is very improbable that even simple self-replicators should emerge on any Earth-like planet. Attempts to create life in the laboratory by mixing water with gases believed to have been present in the Earth's early atmosphere have failed to get much beyond the synthesis of a few simple amino acids. No instance of abiogenesis (the spontaneous emergence of life from nonlife) has ever been observed.

The oldest confirmed microfossils date from approximately 3.5 billion years ago, and there is tentative evidence that life might have existed a few hundred million years before that; but there is no evidence of life before 3.8 billion years ago. Life might have arisen considerably earlier than that without leaving any traces: there are very few preserved rock formations that old, and such as have survived have undergone major remolding over the eons. Nevertheless, several hundred million years elapsed between the formation of Earth and the appearance of the first known life-forms. The evidence is thus consistent with the hypothesis that the emergence of life required an extremely improbable set of coincidences, and that it took hundreds of millions of years of trial and error, of molecules and surface structures randomly interacting, before something capable of self-replication happened to appear by a stroke of astronomical luck. For aught we know, this first critical step could be a Great Filter.

Conclusively determining the probability of any given evolutionary development is difficult, since we cannot rerun the history of life multiple times. What we can do, however, is attempt to identify evolutionary transitions that are at least good candidates for being a Great Filter—transitions that are both extremely improbable and practically necessary for the emergence of intelligent technological civilization. One criterion for any likely candidate is that it should have occurred only once. Flight, sight, photosynthesis, and limbs have all evolved several times here on Earth and are thus ruled out. Another indication that an evolutionary step was very improbable is that it took a very long time to occur even after its prerequisites were in place. A long delay suggests that vastly many random recombinations occurred before one worked. Perhaps several improbable mutations had to occur all at once in order for an organism to leap from one local fitness peak to another: individually deleterious mutations might be fitness enhancing only when they occur together. (The evolution of *Homo sapiens* from our recent hominid ancestors, such as *Homo erectus*, happened rather quickly on the geological timescale, so these steps would be relatively weak candidates for a Great Filter.)

The original emergence of life appears to meet these two criteria. As far as we know, it might have occurred only once, and it might have taken hundreds of millions of years for it to happen even after the planet had cooled down enough for a wide range of organic molecules to be stable. Later evolutionary history offers additional possible Great Filters. For example, it took some 1.8 billion years for prokaryotes (the most basic type of single-celled organism) to evolve into eukaryotes (a more complex kind of cell with a membrane-enclosed nucleus). That is a long time, making this transition an excellent candidate. Others include the emergence of multicellular organisms and of sexual reproduction.

If the Great Filter is indeed behind us, meaning that the rise of intelligent life on any one planet is extremely improbable, then it follows that we are most likely the only technologically advanced civilization in our galaxy, or even in the entire observable universe. (The observable universe contains approximately 10^{22} stars. The universe might well extend infinitely far beyond the part that is observable by us, and it may contain infinitely many stars. If so, then it is virtually certain that an infinite number of intelligent extraterrestrial species exist, no matter how improbable their evolution on any given

planet. However, cosmological theory implies that because the universe is expanding, any living creatures outside the observable universe are and will forever remain causally disconnected from us: they can never visit us, communicate with us, or be seen by us or our descendants.)

The other possibility is that the Great Filter is still ahead of us. This would mean that some great improbability prevents almost all civilizations at our current stage of technological development from progressing to the point where they engage in large-scale space colonization. For example, it might be that any sufficiently advanced civilization discovers some technology—perhaps some very powerful weapons technology—that causes its extinction.

I will return to this scenario shortly, but first I shall say a few words about another theoretical possibility: that extraterrestrials are out there in abundance but hidden from our view. I think that this is unlikely, because if extraterrestrials do exist in any numbers, at least one species would have already expanded throughout the galaxy, or beyond. Yet we have met no one.

Various schemes have been proposed for how intelligent species might colonize space. They might send out "manned" spaceships, which would establish colonies and "terraform" new planets, beginning with worlds in their own solar systems before moving on to more distant destinations. But much more likely, in my view, would be colonization by means of so-called von Neumann probes, named after the Hungarian-born prodigy John von Neumann, among whose many mathematical and scientific achievements was the concept of a "universal constructor," or a self-replicating machine. A von Neumann probe would be an unmanned self-replicating spacecraft, controlled by artificial intelligence and capable of interstellar travel. A probe would land on a planet (or a moon or asteroid), where it would mine raw materials to create multiple replicas of itself, perhaps using advanced forms of nanotechnology. In a scenario proposed by Frank Tipler in 1981, replicas would then be launched in various directions, setting in motion a multiplying colonization wave. Our galaxy is about 100,000 light-years across. If a probe were capable of traveling at one-tenth the speed of light, every planet in the galaxy could thus be colonized within a couple of million years (allowing some time for each probe that lands on a resource site to set up the necessary infrastructure and produce daughter probes). If travel speed were limited to 1 percent of light speed, colonization might take 20 million years instead. The exact numbers do not matter much, because the timescales are at any rate very short compared with the astronomical ones on which the evolution of intelligent life occurs.

If building a von Neumann probe seems very difficult—well, surely it is, but we are not talking about something we should begin work on today. Rather, we are considering what would be accomplished with some very advanced technology of the future. We might build von Neumann probes in centuries or millennia—intervals that are mere blips compared with the life span of a planet. Considering that space travel was science fiction a mere half-century ago, we should, I think, be extremely reluctant to proclaim something forever technologically infeasible unless it conflicts with some hard physical constraint. Our early space probes are already out there: *Voyager 1*, for example, is now at the edge of our solar system.

Even if an advanced technological civilization could spread throughout the galaxy in a relatively short period of time (and thereafter spread to neighboring galaxies), one might still wonder whether it would choose to do so. Perhaps it would prefer to stay at home and live in harmony with nature. However, a number of considerations make this explanation of the great silence less than plausible. First, we observe that life has here on Earth manifested a very strong tendency to spread wherever it can. It has populated every nook and cranny that can sustain it: east, west, north, and south; land, water, and air; desert, tropic, and arctic ice; underground rocks, hydrothermal vents, and radioactive-waste dumps; there are even living beings inside the bodies of other living beings. This empirical finding is of course entirely consonant with what one would expect on the basis of elementary evolutionary theory. Second, if we consider our own species in particular, we find that it has spread to every part of the planet, and we have even established a presence in space, at vast expense, with the International Space Station. Third, if an advanced civilization

Even if an advanced technological civilization could spread throughout the galaxy in a relatively short period of time, one might still wonder whether it would choose to do so.

has the technology to go into space relatively cheaply, it has an obvious reason to do so: namely, that's where most of the resources are. Land, minerals, energy: all are abundant out there yet limited on any one home planet. These resources could be used to support a growing population and to construct giant temples or supercomputers or whatever structures a civilization values. Fourth, even if most advanced civilizations chose to remain nonexpansionist forever, it wouldn't make any difference as long as there was one other civilization that opted to launch the colonization process: that expansionary civilization would be the one whose probes, colonies, or descendants would fill the galaxy. It takes but one match to start a fire, only one expansionist civilization to begin colonizing the universe.

For all these reasons, it seems unlikely that the galaxy is teeming with intelligent beings that voluntarily confine themselves to their home planets. Now, it is possible to concoct scenarios in which the universe is swarming with advanced civilizations every one of which chooses to keep itself well hidden from our view. Maybe there is a secret society of advanced civilizations that know about us but have decided not to contact us until we're mature enough to be admitted into their club. Perhaps they're observing us as if we were animals in a zoo. I don't see how we can conclusively rule out this possibility. But I will set it aside in order to concentrate on what to me appear more plausible answers to Fermi's question.

The more disconcerting hypothesis is that the Great Filter consists in some destructive tendency common to virtually all sufficiently advanced technological civilizations. Throughout history, great civilizations on Earth have imploded—the Roman Empire, the Mayan civilization that once flourished in Central America, and many others. However, the kind of societal collapse that merely delays the eventual emergence of a space-colonizing civilization by a few hundred or a few thousand years would not explain why no such civilization has visited us from another planet. A thousand years may seem a long time to an individual, but in this context it's a sneeze. There are probably planets that are billions of years older than Earth. Any intelligent species on those planets would have had ample time to recover from repeated social or ecological collapses. Even if they failed a thousand times before they succeeded, they still could have arrived here hundreds of millions of years ago.

The Great Filter, then, would have to be something more dramatic than run-of-the mill societal collapse: it would have to be a terminal global cataclysm, an existential catastrophe. An existential risk is one that threatens to annihilate intelligent life or permanently and drastically curtail its potential for future development. In our own case, we can identify a number of potential existential risks: a nuclear war fought with arms stockpiles much larger than today's (perhaps resulting from future arms races); a genetically engineered superbug; environmental disaster; an asteroid impact; wars or terrorist acts committed with powerful future weapons; superintelligent general artificial intelligence with destructive goals; or high-energy physics experiments. These are just some of the existential risks that have been discussed in the literature, and considering that many of these have been proposed only in recent decades, it is plausible to assume that there are further existential risks we have not yet thought of.

The study of existential risks is an extremely important, albeit rather neglected, field of inquiry. But in order for an existential risk to constitute a plausible Great Filter, it must be of a kind that could destroy virtually any sufficiently advanced civilization. For instance, random natural disasters such as asteroid hits and supervolcanic eruptions are poor Great Filter candidates, because even if they destroyed a significant number of civilizations, we would expect some civilizations to get lucky; and some of these civilizations could then go on to colonize the universe. Perhaps the existential risks that are most likely to constitute a Great Filter are those that arise from technological discovery. It is not far-fetched to imagine some possible technology such that, first, virtually all sufficiently advanced civilizations eventually discover it, and second, its discovery leads almost universally to existential disaster.

So where is the Great Filter? Behind us, or not behind us?

If the Great Filter is ahead of us, we have still to confront it. If it is true that almost all intelligent species go extinct before they master the technology for space colonization, then we must expect that our own species will, too, since we have no reason to think that we will be any luckier than other species. If the Great Filter is ahead of us, we must relinquish all hope of ever colonizing the galaxy, and we must fear that our adventure will end soon—or, at any rate, prematurely. Therefore, we had better hope that the Great Filter is behind us.

What has all this got to do with finding life on Mars? Consider the implications of discovering that life had evolved independently on Mars (or some other planet in our solar system). That discovery would suggest that the emergence of life is not very improbable. If it happened independently twice here in our own backyard, it must surely have happened millions of times across the galaxy. This would mean that the Great Filter

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is less likely to be confronted during the early life of planets and therefore, for us, more likely still to come.

If we discovered some very simple life-forms on Mars, in its soil or under the ice at the polar caps, it would show that the Great Filter must come somewhere after that period in evolution. This would be disturbing, but we might still hope that the Great Filter was located in our past. If we discovered a more advanced life-form, such as some kind of multicellular organism, that would eliminate a much larger set of evolutionary transitions from consideration as the Great Filter. The effect would be to shift the probability more strongly against the hypothesis that the Great Filter is behind us. And if we discovered the fossils of some very complex life-form, such as a vertebrate-like creature, we would have to conclude that this hypothesis is very improbable indeed. It would be by far the worst news ever printed.

Yet most people reading about the discovery would be thrilled. They would not understand the implications. For if the Great Filter is not behind us, it is ahead of us. And that's a terrifying prospect.

So this is why I'm hoping that our space probes will discover dead rocks and lifeless sands on Mars, on Jupiter's moon Europa, and everywhere else our astronomers look. It would keep alive the hope of a great future for humanity.

Now, it might be thought an amazing coincidence if Earth were the only planet in the galaxy on which intelligent life evolved. If it happened here, the one planet we have studied closely, surely one would expect it to have happened on a lot of other planets in the galaxy—planets we have not yet had the chance to examine. This objection, however, rests on a fallacy: it overlooks what is known as an "observation selection effect." Whether intelligent life is common or rare, every observer is guaranteed to originate from a place where intelligent life did, in fact, arise. Since only the successes give rise to observers who can wonder about their existence, it would be a mistake to regard our planet as a randomly selected sample from all planets. (It would be closer to the mark to regard our planet as a random sample from the subset of planets that did engender intelligent life, this being a crude formulation of one of the saner ideas extractable from the motley ore referred to as the "anthropic principle.")

Since this point confuses many, it is worth expanding on it slightly. Consider two different hypotheses. One says that the evolution of intelligent life is a fairly straightforward process that happens on a significant fraction of all suitable planets. The other hypothesis says that the evolution of intelligent life is extremely complicated and happens perhaps on only one out of a million billion planets. To evaluate their plausibility in light of your evidence, you must ask yourself, "What do these hypotheses predict I should observe?" If you think about it, both hypotheses clearly predict that you should observe that your civilization originated in places where intelligent life evolved. All observers will share that observation, whether the evolution of intelligent life happened on a large or a small fraction of all planets. An observation-selection effect guarantees that whatever planet we call "ours" was a success story. And as long as the total number of planets in the universe is large enough to compensate for the low probability of any given one of them giving rise to intelligent life, it is not a surprise that a few success stories exist.

If—as I hope is the case—we are the only intelligent species that has ever evolved in our galaxy, and perhaps in the entire observable universe, it does not follow that our survival is not in danger. Nothing in the preceding reasoning precludes there being steps in the Great Filter both behind us *and* ahead of us. It might be extremely improbable both that intelligent life should arise on any given planet and that intelligent life, once evolved, should succeed in becoming advanced enough to colonize space.

But we would have some grounds for hope that all or most of the Great Filter is in our past if Mars is found to be barren. In that case, we may have a significant chance of one day growing into something greater than we are now.

In this scenario, the entire history of humankind to date is a mere instant compared with the eons that still lie before us. All the triumphs and tribulations of the millions of people who have walked the Earth since the ancient civilization of Mesopotamia would be like mere birth pangs in the delivery of a kind of life that hasn't yet begun. For surely it would be the height of naïveté to think that with the transformative technologies already in sight—genetics, nanotechnology, and so on—and with thousands of millennia still ahead of us in which to perfect and apply these technologies and others of which we haven't yet conceived, human nature and the human condition will remain unchanged. Instead, if we survive and prosper, we will presumably develop some kind of posthuman existence.

None of this means that we ought to cancel our plans to have a closer look at Mars. If the Red Planet ever harbored life, we might as well find out about it. It might be bad news, but it would tell us something about our place in the universe, our future technological prospects, the existential risks confronting us, and the possibilities for human transformation—issues of considerable importance.

But in the absence of any such evidence, I conclude that the silence of the night sky is golden, and that in the search for extraterrestrial life, no news is good news. TR

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REVIEWS

COMPUTING

Riding D-Wave

A PIONEER OF QUANTUM COMPUTING ASKS: HAS A CANADIAN STARTUP REALLY DEMONSTRATED A PROTOTYPE FOR A WORKING, COMMERCIALLY VIABLE QUANTUM COMPUTER?

By SETH LLOYD

D-WAVE SYSTEMS' DEMONSTRATION, IN FEBRUARY AND NOVEMBER 2007, OF 16-QUBIT AND 28-QUBIT ADIABATIC QUANTUM COMPUTERS

Computers process information by breaking it down into the smallest possible chunks, called "bits." A bit represents the distinction between two possibilities: True and False, Yes and No, or, as they are conventionally represented, 0 and 1.

The end point of Moore's Law (which holds that computers get faster by a factor of two every year and a half or so) is a computer so powerful that it uses individual atoms to store bits of information: one atom, one bit. If we were able to work at subatomic scales and store bits on electrons or quarks, we might go further. But let's stick with what we *know* we can do.

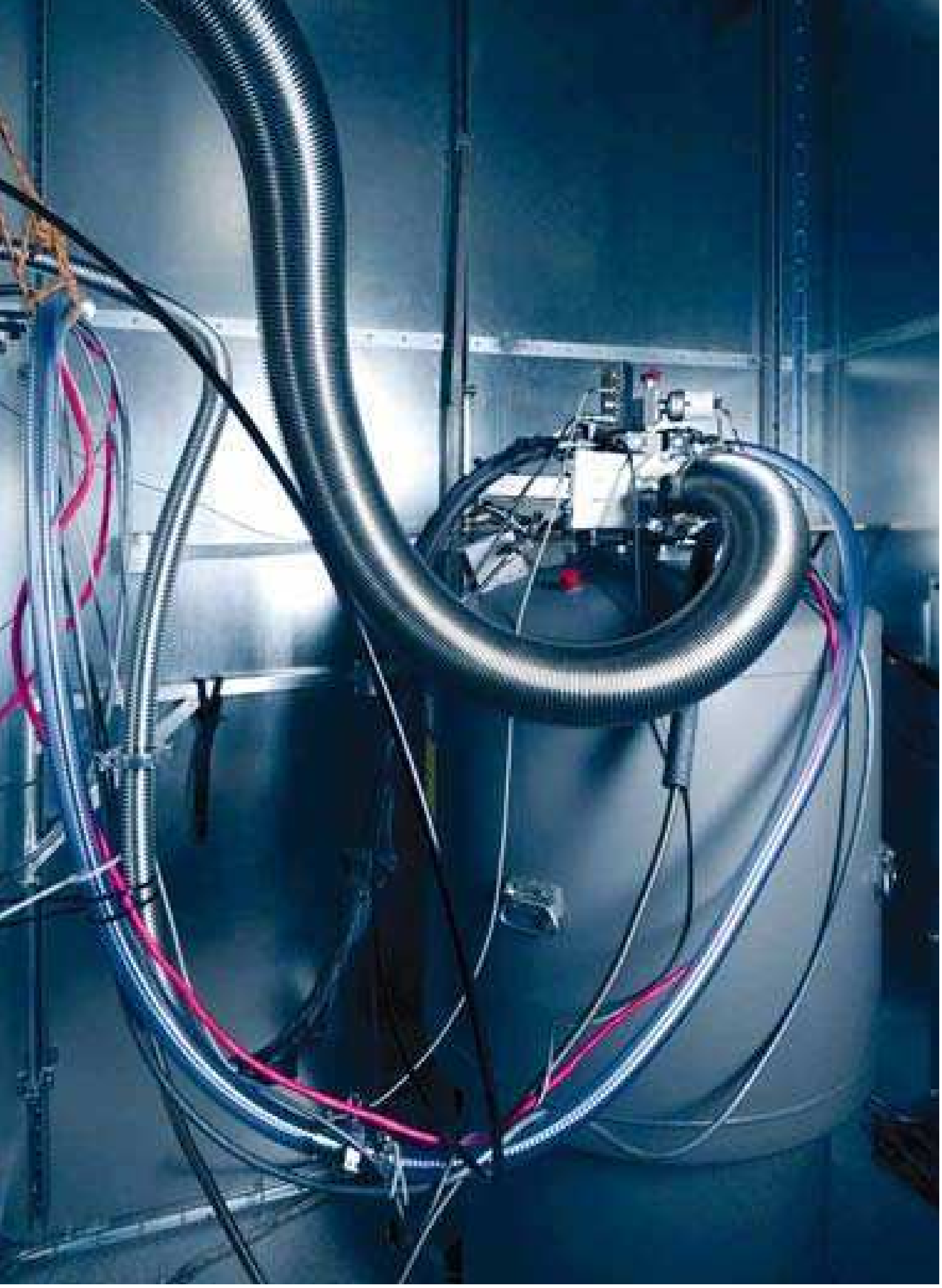
If current rates of miniaturization persist, your PC will store one bit on one atom sometime around 2050. But it's natural to ask whether we can, in fact, achieve a bit-to-atom correspondence. Remarkably, prototype computers that store bits on individual atoms already exist in the laboratory. These computers are called quantum computers, because they store and process information at scales where the laws of quantum mechanics hold sway.

Quantum mechanics is the branch of physics that governs what happens at very small scales. Its principles are famously weird, so it's natural that quantum computers should be odd, too. A conventional electronic computer, in which each bit registers either 0 or 1, is enslaved by binary logic; but a quantum bit, or "qubit," can register 0 and 1 at the same time, a phenomenon known as "superposition." What does it mean for a quantum bit to simultaneously register 0 and 1? The accurate answer is, nobody knows for sure. The counterintuitive nature of quantum mechanics prevents our minds from grasping how quantum bits behave. Nonetheless, because the laws of quantum mechanics are precisely formulated, we can predict what quantum computers will do.

And what they do is remarkable. Since one qubit can simultaneously represent two different values, two qubits can simultaneously represent four (00, 01, 10, and 11, in binary notation); four qubits can represent 16 values; eight qubits 256 values; and so on. Even a relatively small quantum computer, one that had a few tens of thousands of qubits, could consider so many different values at once that it would be able to break all known codes commonly used for secure Internet communication. Quantum computers might also be used for faster database searches, or to tackle hard problems that classical computers couldn't solve with all the time in the universe. My colleagues at MIT and I have been building simple quantum computers and executing quantum algorithms since 1996, as have other scientists around the world. Quantum computers work as promised. If they can be scaled up, to thousands or tens of thousands of qubits from their current size of a dozen or so, watch out!

Given their power to intercept and disrupt secret communications, it is not surprising that quantum computers have the attention of various U.S. government agencies. The National Security Agency, which supports research in quantum computing, candidly declares that given its interest in keeping U.S. government communications secure, it is loath to see quantum computers built. On the other hand, if they can be built, then it wants to have the first one.

Quantum computation has also attracted commercial interest. At current rates of progress, big, code-breaking quantum computers are at least a decade away, so the private sector is focusing on two types of quantum computation that are easier. The first nontrivial type of quantum computing was proposed by the Nobel laureate Richard Feynman in 1981. Feynman was studying how quantum processes in high-energy physics could be simulated. He noted that classical computers were bad at the job, for the same reason that human beings find quantum mechanics counterintuitive: there is no easy way for either to represent a bit that registers 0 and 1 at the same time. Feynman suggested that if the computer were quantum-mechanical, it might have an easier time dealing with



COOL COMPUTER A device known as a dilution refrigerator (shown here) is used to initialize D-Wave's quantum computer, bringing it to its ground state by cooling it to near absolute zero.

KRISTOPHER GRUNERT

quantum processes. In 1996, I showed that Feynman was correct and created algorithms that would allow a quantum computer to simulate solid-state, chemical, and high-energy systems. Such a simulator would require only a hundred qubits or so to be able to surpass all conventional supercomputers.

A second type of quantum computing, known as adiabatic quantum computing, is not only easier than code breaking but potentially far more powerful. Adiabatic quantum computing is a particularly physical way of trying to solve hard problems.

Like all physical systems, electrons would rather inhabit lower energy states than higher energy states, particularly at low temperatures. The energy of a physical system such as an electron depends on the states of its neighbors. One electron might tell its spinning neighbors, "For a lower energy, spin clockwise." Another electron might say, "For a lower energy, spin counterclockwise." The lowest energy state for the spinning electrons as a community is the one that minimizes the total number of conflicts between neighboring spins. For a group of electrons to find their communal lowest energy state, or "ground state," they must find ways to agree on how to align their spins. In the same way that a complex computational problem can be broken down into flipping bits, it can be posed in terms of finding the ground state of a suitable physical system.

Adiabatic quantum computation attempts to represent problems as the disturbance of a quantum system, so that the answer is represented by the system's assumption of a new ground state. Developed by Eddie Farhi and Jeffrey Goldstone at MIT and Sam Gutmann at Northeastern University, it works by initializing the quantum system to a simple ground state (all spins rotating clockwise, for example) and then gradually, or "adiabatically," turning on the interactions that encode the problem. If this turning-on process is sufficiently slow, the system will gradually "ooze" from its simple initial state into the complex final state.

The most interesting aspect of adiabatic quantum computation is that no one knows for sure whether it works in practice. It may be that for any meaningful problem, the system would have to ooze so slowly that it would take the age of the universe to return an answer. Conversely, it may be that even the hardest problem will succumb to an adiabatic quantum computer. Despite the concerted attention of a bevy of physicists and mathematicians, the question of whether adiabatic quantum computing works remains open. Most experts suspect that it can't solve the very hardest computational problems. But suspicion is not proof.

When the theorists can't agree, experimentalists forge ahead. Because the whole point of adiabatic quantum computation is to go slow rather than fast, adiabatic quantum computers are in principle significantly easier to build than general-purpose code-breaking quantum computers. Realizing this key point, in 2002 my graduate student Bill

Kaminsky and I created a design for an adiabatic quantum computer based on superconducting technology. Last year, D-Wave Systems, a quantum-computing startup in Burnaby, British Columbia, announced that it had constructed an adiabatic quantum computer based on our design. At that point, things got interesting.

D-Wave was founded a little less than a decade ago, with the express purpose of building a commercial quantum computer. After toying with the idea of building a quantum computer to factor large numbers, its researchers sensibly settled on the more straightforward and still potentially profitable tasks of quantum simulation and adiabatic quantum computing. In February 2007, at Silicon Valley's Computer History Museum, the company demonstrated a 16-qubit device that it claimed could solve reasonably complex optimization problems. It could even do Sudoku puzzles!

D-Wave has raised about $60 million in funding from venture capitalists such as Draper Fisher Jurvetson. As a private company, it is responsible primarily to its investors rather than to the scientific community. So it was no surprise that in announcing its success in building an adiabatic quantum computer, D-Wave focused on commercial applications rather than scientific details. While venture capitalists were impressed by the announcement, treating the company to another round of funding, scientists were less excited. The press release provided no device specifications that would allow the scientific accuracy of its claims to be assessed. It seemed possible that the computer was simply finding solutions by being cooled down to its ground state, a fairly dull and not-so-quantum-mechanical process, rather than performing the more subtle adiabatic procedure described above. When D-Wave neglected to supply any concrete evidence that the device was actually performing a quantum computation, even the most charitable scientific observers simply assumed that its scientists didn't know whether it was or not. *(See "Desultory D-Wave," p. 11.)*

Less charitable observers uttered words I cannot report in this publication. For my part, I was conflicted. I would *really* like to know whether adiabatic quantum computation works. Even if this approach can't solve the very hardest problems, if D-Wave's system could perform a well-defined demonstration of adiabatic quantum computation in some simple instances, that would be a validation of Kaminsky's and my design. As matters stood, however, D-Wave seemed to be muddying the quantum well for money.

THEY ADMITTED THEY COULD NOT PROVE THAT WHAT THEY WERE DOING WAS TRUE ADIABATIC QUANTUM COMPUTATION. HOW, THOUGH, COULD THEY ANSWER THE QUESTION CONCLUSIVELY?

Last fall, the waters became clearer. D-Wave's chief theoretician, Mohammad Amin, and its chief experimentalist, Andrew Berkley, visited the quantum-computing community at MIT. They discussed the scientific issues frankly. No, they admitted, they couldn't prove that what they were doing was true adiabatic quantum computation—but it looked as if it probably was. How could they answer the question conclusively?

The pioneers of superconducting quantum computation had been able to demonstrate the quantum nature of their devices by zapping them with fast microwave pulses and looking at their responses. But those devices weren't adiabatic; they operated at speeds comparable to those of a conventional computer. The D-Wave device, by contrast, is purposefully slow: therefore, no zapping is possible. As a result, there are a limited number of experiments that can indicate whether the device is really doing quantum computation. One, however, is to vary the slowness with which the device oozes from its initial state to its final state. Halfway through the oozing process, the computer arrives at a point where it must start making the hard choices that lead to the problem's solution. Here the computer is in a weird quantum state, in which every bit registers 0 and 1 at the same time. I urged the D-Wave researchers to explore this critical point and search for the telltale signs.

More recently, I spoke with Herb Martin, the CEO of D-Wave, and Geordie Rose, the company's chief technology officer and cofounder, and emphasized the need for them to pursue these experiments if they are truly interested in explaining how their devices work. One experiment that I recommended to Rose is a specific protocol for creating and verifying the presence of a so-called Schrödinger's-cat state, a specific instance of the state in which all the qubits register both 0 and 1 simultaneously. (The name comes from a thought experiment proposed by one of the founders of quantum mechanics, Erwin Schrödinger, who imagined a quantum cat that could be both dead and alive at the same time.) Both Martin and Rose seem enthusiastic: they are well aware that if they can't prove that their device is really doing something quantum-mechanical, then their name within the scientific community will remain mud.

In November of last year, D-Wave demonstrated what it claimed was a 28-qubit adiabatic quantum computer. Now, the company's scientists are attempting to demonstrate the fundamentally quantum-mechanical nature of their device. There is a strong motivation for doing the science and getting it right. Engineering is science so well established that even engineers like me can do it. If you can't get the science of a 16-qubit quantum computer right, then your chances of building 512-qubit and 1,024-qubit devices (D-Wave's next planned steps) are nil. On the other hand, if D-Wave can confirm that its current system enters the state where all its qubits are 0 and 1 at the same time, then it has a good shot at building quantum devices that are more complex.

And a 16-qubit superconducting Schrödinger's cat would be pretty cool. TR

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INTERNET COMMERCE

Recommendation Nation

LEARNING TO LOVE CUSTOMERS LIKE YOU.

By MICHAEL SCHRAGE

I love books, I like music, and I don't mind the news. When I'm sent a link to something a friend thinks I should read, hear, or view, I take it seriously. Recommendations are essential to my quality of life.

It's a good thing I feel this way, because recommendations are everywhere on the Internet. Wherever I shop online, some sliver of my screen is prompting me with a come-hither like "*Customers who bought this item also* … ." Pop-ups and context-sensitive advertisements have been supplemented by this low, seductive whisper of automated suggestion. The truth is that I now get more good recommendations about more things, more often, from Bayesian algorithms than from my best friends. Perhaps this should make me wistful, but it doesn't. Better technology doesn't mean worse friends.

AMAZON'S "CUSTOMERS WHO BOUGHT THIS …" RECOMMENDATION ENGINE
www.amazon.com

APPLE ITUNES' "JUST FOR YOU" RECOMMENDATION ENGINE
www.apple.com/itunes

Unlike human recommenders, Apple.com, Amazon.com, and Google.com never insult me by implying that I spend my time, money, or attention on the wrong things. They're simply making relevant—and occasionally novel—recommendations based on my past choices and the things I attend to in real time. The focus of digital personalization has shifted from what I am interested in *now* to what I might be interested in *next*. All the choices I make in the moment are absorbed into a sphere of suggestion where, after they have been statistically weighted, they are reborn as offers and advice.

Increasingly, I find myself as curious about a site's recommendations as about what it sells. That a site is trying to sell me something else seldom annoys me. On the contrary, I like it that Internet companies have dedicated such ingenuity, memory, and processing power to offering me good suggestions. But "good" needs to get much better if recommendations are to expand beyond telling me what I might like right now.

Consider Amazon, whose site displays some of the irksome limitations of current recommendation engines. The company has been a pioneer in this technology since shortly after its launch in 1995. Greg Linden, who is now with Microsoft, helped write Amazon's first recommendation engine, Instant Recommendations, which succeeded where an older system called BookMatcher had failed. The engine evolved incrementally. "We learned what worked and what didn't by seeing how changes in the recommendations helped people find new books," Linden says. "We enjoyed helping people discover books they probably would not have found on their own. It was never about marketing—just matching people to books they would love. But it turns out people do buy more when you help them find what they need."

Today, Amazon makes recommendations on the basis of a customer's browsing and buying history, other items viewed or purchased by customers who've bought the product being viewed, and items that seem related to that product. On Amazon, reviews, recommendations, and rankings become an essential part of browsing and shopping. For example, while I was checking out *Predictably Irrational*, Daniel Ariely's new book about apparently dysfunctional decision making, the "Customers Who Bought This Item Also Bought …" strip tipped me off to a forthcoming title I had never heard of: *Nudge*, by the University of Chicago behavioral economist Richard Thaler and the University of Chicago law professor Cass Sunstein. Click, and I'm there. It's precisely the sort of real-time connection that makes Amazon shopping superior to both in-person and online alternatives.

Click-throughs are the currency of the recommendation nation. The more choices you make (or decline to make), the more finely tuned the recommendations become. The more your peers interact with Amazon, the better Amazon's engines can infer which recommendations will make the most sense for you and the most dollars for them. The result is that recommendations can become breathtakingly profitable examples of what economists call "network effects," where a network's value is proportional to the number of its participants.

But as useful as these algorithms can be, they're also subject to sudden bouts of apparent blindness. It ticks me off, for example, that Amazon's recommendation engines do not intelligently distinguish the books I browse or buy for *me* from the ones I browse or buy as *gifts*. Yes, I can click a little box when I buy something as a gift. Additionally, if I visit "My Amazon," there is a tab that offers to "improve my recommendations": on the long scroll of everything I have bought, I can click a box that says "This was bought as a gift" and another box that says "Don't use for recommendations." But these features are far from obvious (I discovered them only in writing this review, and I use Amazon a *lot*). Nor do Amazon's engines use my history of gift buying to suggest presents for particular friends. Would such suggestions bug me? No. In fact, I'd like Amazon to make it easy for me to switch back and forth between browsing for myself and browsing for others. I'd cheerfully choose to be a recommendation beta user if such an option were offered—much as I'd be happy to have a "personal shopper" help me out come birthdays and holidays. Just ask *nice*.

Different issues emerge with the "Just for You" recommendation engine at Apple's iTunes, which was introduced in 2005. I can

forgive the fact that my purchase of *Bohemian Rhapsody* prompted "Just for You" to recommend *The Best of Foreigner Live*, but not that buying Van Halen's "Dance the Night Away" provoked a recommendation for Rush. While I accept that recommendation engines have their own quantitative quirks and eccentricities, those suggestions are just terrible. Apple's engine appears to give more weight to era than it does to genre, tempo, or style. (An Apple spokesperson whom I contacted declined to be more specific about how its recommendation engines work.)

Apple's recommendation software is worse than Amazon's in other ways, too. When I buy a song or two from one band, why does the engine ask if I want to buy an entire album from another? I should get individual song recommendations before I get album suggestions. Apple's iTunes pushes albums *and* songs: it feels like a hard sell. I want to be sonically seduced, not commercially assaulted. Get me to sample—for free, of course—another song before asking if I own or want to own the entire album. If I like the song, I'll buy it. Honest!

The "Just for You" interface looks pretty enough. But as an interactive experience, it's displeasing. Unlike Amazon, the site feels more like a record shop that wants to move product than the den of a friend with great taste in music. Recommendation engines should liberate retailers from bad online store design, but the iTunes site reminds me of what I like least about shopping. Where is Jonathan Ive, Apple's legendary industrial designer, when we need him?

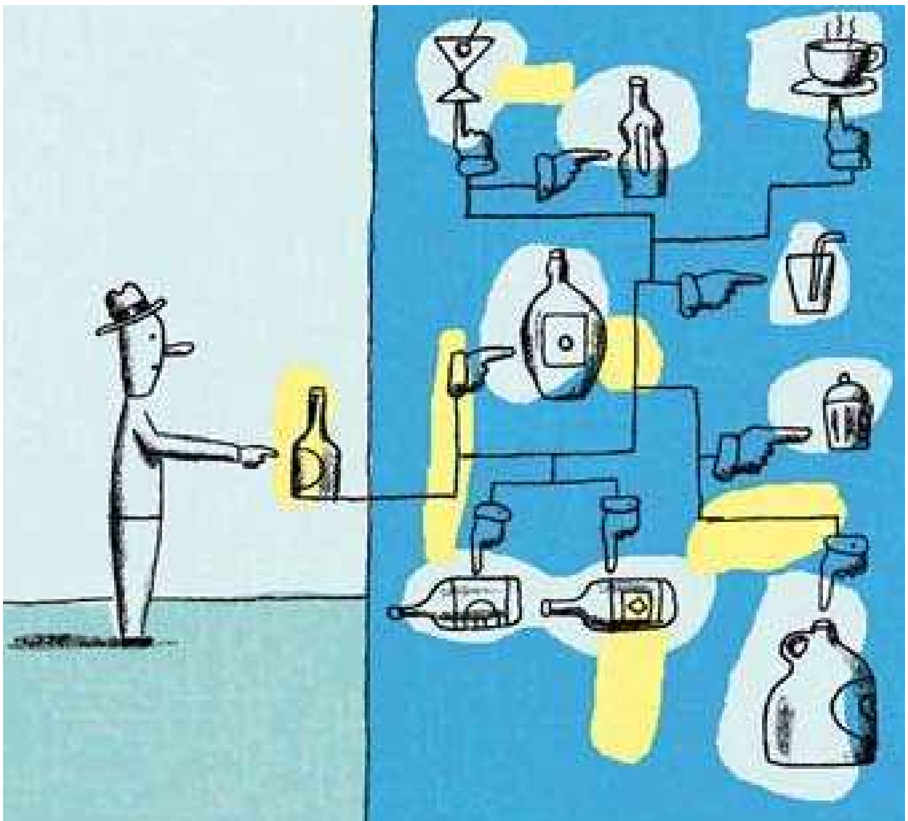
These complaints notwithstanding, my bet is that recommendation algorithms and interfaces will rapidly branch out. In the future, perhaps Google's Gmail will tell you whom you should forward that urgent e-mail to, or remind you to keep in touch with a friend you've inadvertently ignored. Marrying Gmail's context-sensitive advertising to a decent recommendation engine would boost the value of both. What's more, it's easy to imagine Facebook suggesting what information should be shared with whom—or who should be sharing more with you.

The rise of the social graph (an abstract representation of the social connections between users of digital networks; see "Between Friends," March/April 2008 and at TechnologyReview.com) should enable different companies' recommendation engines to work together, offering financial advice, travel options, and more. Wouldn't it be intriguing to see what stocks and funds people like you bought? Perhaps these technologies will ultimately go meta, with some startup offering recommendation engines that let you pick the best recommendation engines for you. Advice about advice might be a great business.

For all my excitement about the future of recommendation services, I can't help feeling the way I felt about search in 2001. Existing recommendation engines have a lot of value, but they're still primitive. Distinctions between browsing and comparison (that is, between looking at products and choosing between them) are poorly understood. We've yet to see how user-generated tags make product and service descriptions more precise and useful. The more specific, explicit, and time-sensitive the tag, the better the potential recommendations will be.

Smart people all over the world are working on these problems. Billions of dollars are at stake. Netflix is offering a million dollars to anyone who can improve the efficacy of its (exceptionally successful) recommendation engine. That's a small price to pay for a company whose future depends on its ability to compete with Blockbuster and the digital video delivery companies of the future. It is an interesting and important problem, because it's not only individuals who watch the movies, but couples, families, and friends. Perhaps the winning algorithm will be optimized for the preferences of groups.

When I get good recommendations, I spend my time and money differently. Even better recommendations will dramatically increase the value of that time and money. That's a digital future I crave and expect. I hope Internet innovators take my recommendations as seriously as I take theirs. TR



MARC ROSENTHAL

MICHAEL SCHRAGE IS A CONSULTANT ON INNOVATION, A RESEARCHER AT MIT'S SLOAN SCHOOL, AND THE AUTHOR OF *SERIOUS PLAY: HOW THE WORLD'S BEST COMPANIES SIMULATE TO INNOVATE*.

TELECOMMUNICATIONS

The State of the Global Telecosm in 2008

HOW THE MOST NOTORIOUS PROMOTER OF THE 1990s TELECOMMUNICATIONS BOOM HAS BEEN PROVED RIGHT.

By MARK WILLIAMS

This past February, with the Southern California days already warm and the sunlight reflecting off the bay and the high-rises along the waterfront, 12,000-odd members of what is perhaps the most important technology industry on the planet converged on San Diego's convention center for their annual conference.

Since 2005 this event has been called the Optical Fiber Communication Conference and Exposition and the National Fiber Optic Engineers Conference. It's a mind-numbingly dull name with an unpronounceable acronym (OFC/NFOEC). But the nearly one terameter (1,000 million kilometers) of fiber-optic cable encircling the earth effectively makes up our global civilization's central nervous system, since it carries Internet traffic and all international telecommunications—including voice calls, which nowadays are transmitted as packets of digital data. The world's data traffic, moreover, is doubling in volume every two years. Industry critic Robert X. Cringely claims that the only reason video didn't overwhelm U.S. Internet services in 2007 was that broadband ISPs capped bandwidth and closed switches to control traffic, while pretending that they were taking no such measures. People have been predicting that the Internet would crash as long as it's existed, of course. Still, it's worth considering that if, for instance, all of YouTube's users were to upload their videos in high definition, it would nearly double U.S. Internet traffic.

I went to San Diego because I wanted a better picture of the state of the global telecosm in 2008. What's a telecosm? As I entered the convention center on the conference's third morning, I ran into an older gentleman dressed in a blue blazer and beige chinos, trying irritably to get into the main hall. Recognizing him, I said, "You're George Gilder." Tetchily, the bespectacled gentleman acknowledged that he was. "This is most annoying," he told me. "It's this way," I said, pointing, and left him. It was a poignant moment: a few short years before, the convention's officials would likely have sent a limousine and had someone waiting to usher Gilder to his seat. Back then, he'd been a wealthy, honored prophet of technology. In 2000—the year communications carriers and technology suppliers saw their stock begin to collapse—he'd published a book called *Telecosm* (whose original subtitle was *How Infinite Bandwidth Will Revolutionize Our World*). In those days, any company endorsed by Gilder's monthly newsletter—which by the late 1990s mainly endorsed companies involved in the global build-out of optical networks—immediately experienced the "Gilder effect": its stock value surged.

THE OPTICAL FIBER COMMUNICATION CONFERENCE (OFC) AND NATIONAL FIBER OPTIC ENGINEERS CONFERENCE (NFOEC), 2008

Unlike most technology promoters of that era, Gilder was an interesting fellow with a history. He'd begun in the 1960s as a speechwriter whose clients included Richard Nixon; in the 1970s he'd penned an antifeminist screed, called *Sexual Suicide*, that prompted *Time* magazine to name him "the nation's leading male-chauvinist-pig author." After a period promoting supply-side economics in the Reagan era, Gilder established himself as a technology pundit: he published *Microcosm*, which assessed the microchip revolution, in 1989 and *Life after Television*, which predicted that "teleputers" connected by fiber-optic cable would make broadcast television obsolete, in 1990. Gilder hadn't just hit on the coming thing in exquisitely timely fashion, it turned out; he learned so much about the actual technologies that the experts took him seriously.

Gilder argued that just as the microprocessor had introduced previously unimaginable processing power, so the fiber-optic construction boom would usher in a world of instantaneous communication and infinite bandwidth: the telecosm. He predicted that it would make "the CPU ... peripheral, the network central," and that it would enable anyone to launch a product, company, or political movement. But every boom must go bust, and the crash of the telecommunications industry, when it came, proved worse than the bursting of the dot-com bubble. More than $500 billion was lost in just a few years. Between 2001 and 2004, 216 telecommunications companies went bankrupt—most notably Worldcom ($104 billion in assets), whose CEO, Bernie Ebbers, received a 25-year jail sentence for what remains the largest accounting fraud in U.S. history. Meanwhile, hitherto stable industry giants like AT&T staggered. Unfortunately for Gilder, he had loved his tech companies not wisely but too well, investing his own money as he had advised others to do.

"I'm a fan of George Gilder, the bubble bursting notwithstanding," Ethernet coinventor Bob Metcalfe (a member of *Technology Review*'s board of directors) told me after his San Diego keynote speech, "Toward Terabit Ethernet." Metcalfe had told his audience not only that optical networks would soon deliver 40- and 100-gigabit-per-second Ethernet—standards bodies are now hammering out the technical specifications—but also that 1,000-gigabyte-per-second Ethernet, which Metcalfe dubbed "terabit Ethernet," would emerge around 2015. Why, I asked, did Metcalfe believe this? "Last


THIS BIG! George Gilder was a promoter of telecommunications during the boom of the 1990s.

MICHAEL TEMCHINE/THE NEW YORK TIMES/REDUX

night, Gilder spoke to 300 of us at an executive forum about his 'Exaflood' paper, in which he predicts a zettabyte of U.S. Internet traffic by the year 2015," Metcalfe said. "Since I admire Gilder, I extrapolated from his prediction."

FIBER AGLOW

An exabyte is 10^{18} bytes of data; a zettabyte is 10^{21} bytes. Metcalfe pointed to video, new mobile, and embedded systems as the factors driving this rising data flood: "Video is becoming the Internet's dominant traffic, and that's before high definition comes fully online. Mobile Internet just passed a billion new cell phones per year. Then totally new sources of traffic exist, like the 10 billion embedded microcontrollers now shipped annually." Did Metcalfe believe that the existing infrastructure—built in the boom years, when great excesses of fiber-optic cable were laid down—could support terabit Ethernet? "That dark fiber laid down then is being lit up, and some routes are now full," he said. "That's the principal pressure to go to 40 and 100 gigabits per second. It seems we can reach those speeds with basically the same fibers, lasers, photodetectors, and 1,500-nanometer wavelengths we have, mostly by means of modulation improvement. But it's doubtful we'll wring another factor of 10 beyond that." Thus, the backbone networks would need to be overhauled and new technologies implemented.

The speaker after Metcalfe, Herwig Kogelnik, described both the field's progress and the technologies that would support not just 10- and 40-gigabyte-per-second but also terabit speeds. Kogelnik—who in more than four decades at Bell Labs has headed several research divisions investigating lasers, holography, and optical guided-wave devices, collecting too many academic and industry honors to list in less than a page—explained that current research had, for example, advanced WDM (wavelength division multiplexing) technology to a point where economical transmission of 10 channels, each carrying 100-gigabyte-per-second traffic, was now feasible. Likewise, on the tradeshow floor, it was apparent that the component technologies of the telecosm Gilder envisioned a decade ago—a global network with infinite bandwidth and instantaneous transmission—were becoming available in 2008. Companies exhibited products that made use of silicon photonics: Lightwire, for instance, offered a lightweight transceiver designed to greatly improve upon the SFP+ modules currently used to connect servers and network equipment. Since photons move much faster and scatter much less heat than electrons, it promises to reduce power dissipation by more than half.

Nevertheless, many of the conference's attendees and exhibitors seemed ambivalent. Sure, they felt, all this was exciting. Simultaneously, however, they told each other in muted tones that the economy was sinking and the industry needed to undergo consolidation. And who, they asked, would pay the up-front costs for these next-generation networks?

"Nobody wants to pay," Jag Bolaria, a Linley Group analyst and former director with Intel's Ethernet division, told me. "That's why British Telecom is asking the U.K. government for subsidies to install DSL bandwidth. It's the same in France and Italy, and it'll happen here." Bolaria was particularly critical of U.S. carriers. "Test what you get through your broadband connection, and you'll find a one- or two-meg link is what you end up with," he said. "In Europe and even parts of Asia, they're getting significantly more—maybe 10 megs. But in America, carriers own the pipes, and we don't really see much competition. If they don't want to give you much bandwidth—and AT&T and other carriers are selling T1 lines and charging seriously for them—you don't get much bandwidth. Furthermore, the carriers want to control content and charge for that." If the U.S. government gave American telecoms taxpayers' money, Bolaria said, the companies should be strictly prevented from pushing tiered services or content restrictions onto consumers.

He was guardedly optimistic about the future. "We're slowly moving toward more than 25 megs of bandwidth in a fiber-optic pipe into your house," he said. "I think as you start getting two- to five-meg uplinks, then you'll reach the point where users can put their own content in high definition." That, he speculated, might change Hollywood as radically as the Internet had already changed newspapers. "Overall," he said, "I'm looking forward to the time when you can truly choose or create your own content, as opposed to 'This is what you get and how much you pay for it.'"

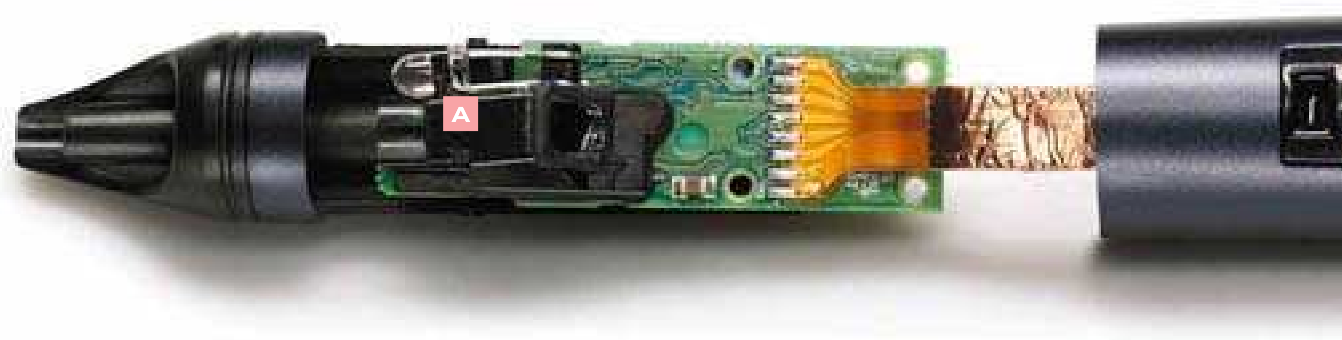
Altogether, the telecosm in 2008 is much as Gilder predicted at the beginning of the century. TR

MARK WILLIAMS IS A CONTRIBUTING EDITOR TO *TECHNOLOGY REVIEW*.

HACK

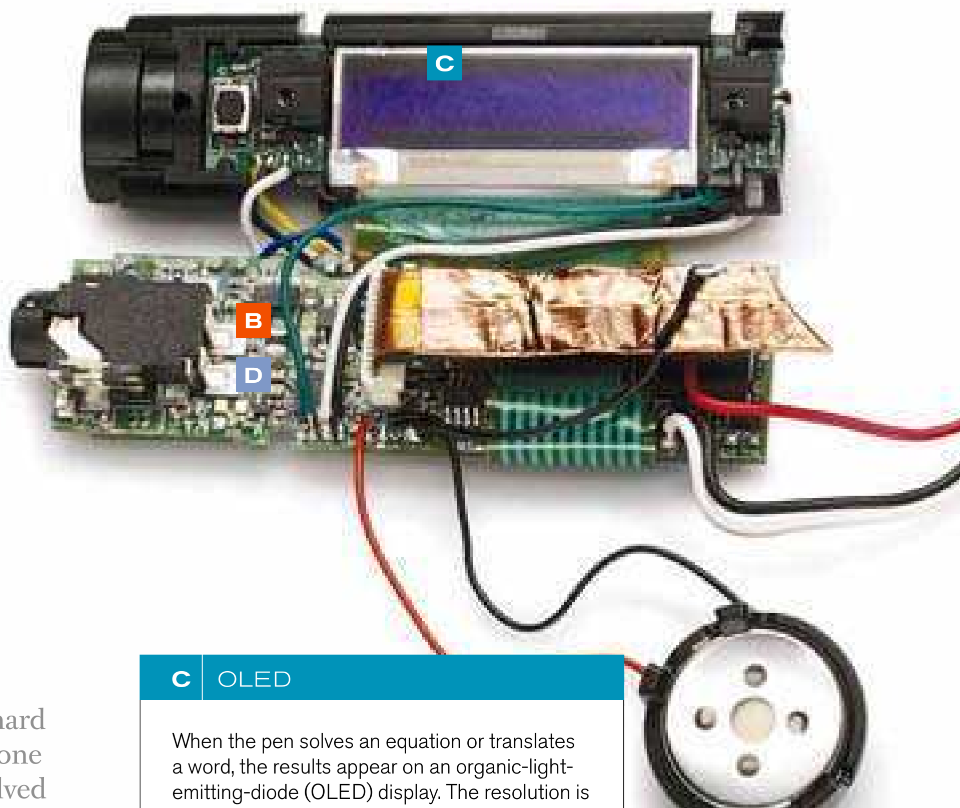
B PROCESSOR

A Samsung Arm 9 processor runs the pen's software, including the algorithms that track its position.



A CAMERA

Seventy times a second, the pen photographs specially printed paper within a radius of seven millimeters, using a camera and an infrared diode behind the point to read a pattern of dots. The pen uses the photographic information to map its location against the complete pattern.



Livescribe Pulse

HANDWRITTEN NOTES GET DIGITAL AUDIO SUPPORT.

By ERICA NAONE

ANYONE who's been a student knows how hard it can be to scribble down everything someone else is saying. This problem is brilliantly solved by the Livescribe Pulse, a computerized pen that records as you write and digitally syncs the audio recording to the notes. Write or draw on specially patterned paper; then tap the pen on a word or sketch, and it will play back what was being said when you made those marks. The pen can also solve equations and define or translate words.

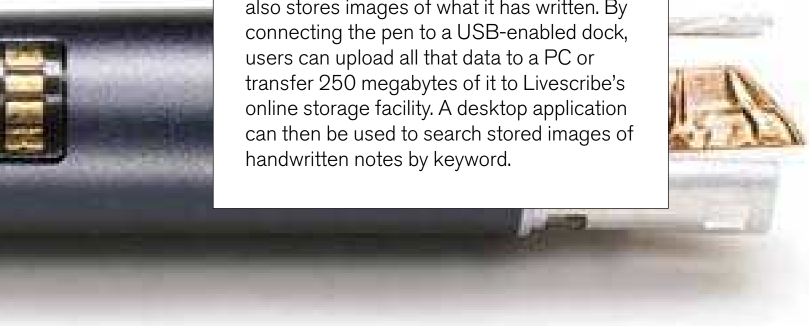
C OLED

When the pen solves an equation or translates a word, the results appear on an organic-light-emitting-diode (OLED) display. The resolution is sharp enough to display kanji characters, says Livescribe's CEO, Jim Marggraff—an important feature for the pen's translation function.

TOBY PEDERSON

D MEMORY

With either one or two gigabytes of memory (depending on the model), the pen can store more than 100 hours of recorded audio. It also stores images of what it has written. By connecting the pen to a USB-enabled dock, users can upload all that data to a PC or transfer 250 megabytes of it to Livescribe's online storage facility. A desktop application can then be used to search stored images of handwritten notes by keyword.



E RECORDING HEADSET

The pen comes with a headset that the user can wear while recording. Microphones in the headset record sound on two tracks, capturing the distinct audio signal received by each ear. When the user plays back the stereo recording, the directional cues make it easier to sort out sounds recorded under less than ideal circumstances, such as a lecture taped from the back of a room.

SOFTWARE DOWNLOADS

Livescribe plans to maintain a clearinghouse online where users can download new applications, some created by the company and others by users. (Anyone who can program in Java can write software for the pen.)

DOT PATTERN

The pen is designed to write on paper printed with a very faint pattern of dots. (A notebook comes with the pen, and users can print the pattern onto plain paper using their own printers.) Licensed from the Swedish company Anoto, the pattern consists of dots about 100 micrometers in diameter, arranged 0.3 millimeters apart. Three square millimeters' worth of dots is enough to define a specific position in the pattern—a position that the pen can track as it moves over the paper. Each printed page has its own unique pattern—actually, a unique portion of a single, nonrepeating pattern big enough to cover Europe and Asia. The pattern can be extended if necessary, so Livescribe doesn't anticipate running out of dots anytime soon.

WWW See how to use this pen: **technologyreview.com/hack.**

Creating a Heart

AN INGENIOUS METHOD FOR MAKING NEW ORGANS COULD ONE DAY REVOLUTIONIZE MEDICAL TRANSPLANTS.

By AMANDA SCHAFFER

In Doris Taylor's cell- and molecular-biology lab at the University of Minnesota, a small pink heart beats in a glass chamber amid a complex of tubes. With each twitch, the heart's bottom tip traces a small curve in space, and pink nutrient solution flows out through the aorta. Remarkably, this living heart was grown in the lab.

Taylor directs the university's Center for Cardiovascular Repair, where her team has created bioartificial hearts using a novel approach in which animal hearts act as scaffolds. The researchers begin with a rat or pig heart and chemically wash away its cells. What remains is the extracellular matrix, a complex of carbohydrates and proteins that preserves the intricate structure of chambers, valves, and blood vessels. The researchers add heart cells harvested from a newborn animal and incubate the organ in a bioreactor, which provides physiological cues like pressure and electrical stimulation. Soon, the heart begins to beat weakly on its own.

The goal is to create hearts and other organs for transplant that use the extracellular matrix of a cadaver's or pig's organ and are populated with a recipient's cardiac progenitor cells. Since the re-created organ would essentially be made from the patient's own cells, it would be compatible with his or her body. In theory, patients would not need harsh immunosuppressant drugs, because the bioartificial hearts would not provoke a strong immune response. "Even though heart transplants are great, you're basically trading one disease for another," says Taylor: immunosuppressants can cause high blood pressure and kidney disease. "Our hope is to overcome that."

The idea of growing new heart tissue to repair heart damage is not new. Numerous groups are working on cell therapies, in which new cells are injected into a specific region of a failing heart to help restore function. In fact, Taylor herself helped pioneer that approach in earlier work at Duke University. Researchers are also developing patches of cardiac tissue that could be sewn to the surface of a sick heart to help it contract more strongly. But both approaches would primarily benefit patients whose heart damage is not very severe, Taylor says. By contrast, Taylor's bioartificial hearts are aimed at patients who need organ transplants to live.

Taylor chose to use real hearts as a starting material because the organ's structure is too complex to build from scratch, at least in the near term. "Nature's already figured out a way to make this scaffold," she says, "so why try to build it when we don't know everything that's there?"

Gordana Vunjak-Novakovic, a professor of biomedical engineering at Columbia University, says that to her knowledge, this is the first time someone has "taken a whole heart and developed a system for stripping it

PHOTOGRAPHS BY JONATHAN CHAPMAN

GROWING HEARTS Doris Taylor and her colleague Stefan Kren are creating live bioartificial hearts. A pig's heart in formaldehyde (below) has been stripped of its cells using a strong chemical detergent. The extracellular matrix left behind will be seeded with cells to produce a new heart. A rat heart in a bioreactor (left) has been chemically stripped of cells and then repopulated with neonatal cardiac myocytes. Suspended in the bioreactor, the new heart receives nutrients; mechanical and electrical cues train it to beat on its own.

fully of cells" in order to create a new, recellularized organ. "It's very significant work," she adds, though it "still has a long way to go" before it could be useful to patients.

COMING ALIVE

To flush the animal heart of cellular material, "we start with a nasty detergent that literally bursts the cells," Taylor says. In the case of larger animal hearts, like those of pigs, a member of the center, Stefan Kren, fills a large receptacle with the detergent and lets it flow into the heart through a long rubber tube. To "decellularize" smaller organs, like rat hearts, Kren uses a piece of enclosed glassware. After cells are removed, the heart appears white and rubbery. Taylor points to a glass jar containing a decellularized pig heart in formaldehyde, noting that the location of the coronary blood vessels is visible. Valves are intact, she says, as are heart chambers.

The bigger challenge is adding new cells to the heart scaffolding and culturing it within the bioreactor. To prepare for this process, Kren places a decellularized rat heart in saline solution and attaches tiny catheters to the left ventricle and aorta. These are for inflow and outflow of nutrient solution, respectively. Then he hangs the organ by the aorta within the bioreactor's central glass chamber, which is surrounded by a system of tubing. He also attaches two electrodes to the heart, one near its bottom and another near the aorta. These will help pace the heart and encourage the new cells to contract in a coördinated fashion.

The next step is particularly tricky: it involves injecting new cells, isolated from newborn rats, through the walls of the left ventricle. (For human hearts, of course, a different cell source, such as cardiac stem

cells, would be needed.) "If we put too few in, they won't interact with each other properly," says Taylor. "If we put too many in, they're not going to get enough oxygen and nutrients and are going to die."

So far, her team has used a primary culture that includes four types of heart cells from neonatal rats: cardiac myocytes, endothelial cells, smooth muscle cells, and fibroblasts. The researchers have repopulated the left ventricle but have yet to complete the process with other heart chambers. Once the cells are in place, Kren begins the electrical pacing. "We usually wait a day while the cells are settling down," he says.

At this stage, the bioreactor mimics several features of a heart-lung system. A gas mixture that is 95 percent oxygen bubbles from a steel tank into a cylinder of nutrient solution. A small pump sends that solution over to the heart, down through the catheter, and into the left ventricle. Not only does the solution provide nutrients, says Taylor, but the pumping action stretches the heart mechanically, the way a heartbeat would. "We want to train the cells so they beat in a way that gets the blood out and don't just sit there and throb," she says.

LEARNING TO BEAT A close-up of the rat heart in the bioreactor shows that it is attached to two catheters responsible for the inflow and outflow of a nutrient solution. The heart is also hooked to two electrodes that train it to contract and expand.

STARTING POINT

The heart in front of Taylor has been in the bioreactor for 10 days. How well would it beat on its own, when only one of its ventricles has been repopulated with cells? Kren switches off the current, and the heart's motion decreases noticeably. Still, a rhythmic twitch is apparent in the left ventricle, indicating that cells there are beating in sync, and that the heart has started to gain some function.

The group has maintained rat hearts in the bioreactor for up to 40 days. In results published in *Nature Medicine*, they reported that after eight days, the hearts were able to generate roughly 2 percent as much force as an adult rat's organ. The researchers hope to improve on this number, in part by adding cells to the scaffold more effectively.

But the next goal is truly daunting: to successfully transplant the hearts into animals. To date, the scientists have implanted hearts in the abdomens of rats for up to seven days. "We needed to show that we could sew them in and that they wouldn't leak," says Taylor. Now, however, the scientists must try to make the re-created organs take the place of the animals' own hearts.

When it comes to making substitute hearts for people, the hurdles are even higher. "Where do we start?" asks Taylor. One of the greatest challenges is finding a suitable source of cells that will repopulate the heart scaffolding. Adult heart muscle cells do not divide readily. And cardiac-derived progenitor cells, which are akin to cardiac stem cells, are not plentiful, although Taylor says her group has had some success isolating them and growing them in the laboratory. A human heart contains trillions of cells, she says. "We don't believe we're going to put every cell back. We believe we're going to put some cells back and let them divide and figure out where they need to be themselves."

If it works—and it will probably be years before that is known—the approach could transform the field of organ transplantation. "One of the best things about this process is that we're harnessing natural processes to make things happen as they do in life," says Kren. "We don't have to do the heavy lifting. Nature will do it for us." TR

WWW Hear Doris Taylor explain the steps involved in rebuilding a heart: **technologyreview.com/demo**

AMANDA SCHAFFER IS A SCIENCE AND MEDICAL COLUMNIST FOR *SLATE* AND A FREQUENT CONTRIBUTOR TO THE *NEW YORK TIMES*.

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Career Growth Profile

Today, Jay Levine is a C-level executive who leads product development for a nationally recognized financial-services firm. He manages a team of 400 employees and oversees a $50 million annual budget. It's a tall order, especially for someone who began his career designing systems for libraries, hospitals, and even the U.S. Secret Service.

"I was a horizontal gunslinger in those years," says Levine, executive vice president and chief technology officer for Wolters Kluwer Financial Services. "I didn't specialize in any one technology or application domain. I focused on enabling technology and applications that were used across multiple domains."

But Levine didn't want to be a systems engineer forever, and he knew he needed to broaden his knowledge base to get ahead. Already, he was a late bloomer of sorts, having waited 10 years into his career to earn a bachelor's degree. He pursued his undergrad degree part time while holding down a full-time job at the Analytic Sciences Corporation (TASC). As soon as he reached that goal, Levine set his sights on a master's degree in information systems at George Mason University.

"TACS is a high-end engineering firm for the intelligence community; when I was there, they were very proud that 70 percent of their employees had doctoral degrees," Levine says. "I knew that to move up in management, I needed more education."

Jay Levine

Age: 51

Job Title: EVP and CTO

Employer: Wolters Kluwer Financial Services

Program: MS, technology management, University of Minnesota, 2003; MS, information systems, George Mason University, 1996

To learn more about Jay's decision to continue his education—and how it helped him move up the corporate ladder, go to
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FROM THE LABS

INFORMATION TECHNOLOGY

Power Walking

KNEE BRACE COLLECTS ENERGY FROM ITS USER'S STRIDE

SOURCE: "BIOMECHANICAL ENERGY HARVESTING: GENERATING ELECTRICITY DURING WALKING WITH MINIMAL USER EFFORT"
Max Donelan et al.
Science 319: 807–810

Results: Scientists at Simon Fraser University in British Columbia have designed a knee brace that can harvest as much as 13 watts of power from the energy of its wearer's strides, enough to charge 30 phones simultaneously.

Why it matters: With the proliferation of small gadgets that need to be charged, engineers are looking for alternatives to electrical outlets for charging. Researchers had already made shoe-embedded generators that are easy to use, but they don't collect more than a watt of power, making them impractical.

Methods: The researchers looked at the biomechanics of the human gait and saw that at the end of a stride, a person must actually exert energy to slow his or her moving leg. When the brace's generator is engaged, it helps slow the leg for the wearer, capturing energy in much the same way that a hybrid car harvests power from braking.

Rather than forcing the wearer to work harder to produce extra energy, the brace reduces the effort exerted at the end of a stride. A sensor in the device monitors the angle of the knee to turn the generator on and off so that it doesn't impede motion in the early part of a stride, when the knee is accelerating.

Next steps: The prototype device weighs just over three pounds; a spinoff company, Bionic Power, is developing a lightweight model.

The biomechanical energy harvester comprises an aluminum chassis and generator mounted on a customized orthopedic knee brace.

GREG EHLERS/SFU

Better Phase-Change Memory

IMPROVED TECHNOLOGY COULD COMPETE WITH FLASH

SOURCE: "A MULTI-LEVEL-CELL BIPOLAR-SELECTED PHASE-CHANGE MEMORY"
Ferdinando Bedeschi et al.
International Solid-State Circuits Conference, February 3–7, 2008, San Francisco

Results: Researchers at Intel and STMicroelectronics have developed an algorithm that doubles the amount of data that can be stored in a single phase-change memory cell, which represents bits as distinct arrangements of a material's atoms.

Why it matters: For the past decade, flash memory has provided compact, sturdy storage for small devices such as iPods and cell phones. But flash chips, which store data as electric charge, may soon reach the limits of their capacity. Phase-change memory is among the alternatives that engineers have been pursuing. Previously, a phase-change memory cell could represent only one bit of data at a time. But the researchers found a way to store two bits in each cell, doubling the capacity of phase-change memory and making it competitive with flash.

Methods: A typical phase-change memory cell uses a type of glass that can switch back and forth between amorphous and crystalline states; the crystalline state represents a 1, the amorphous state

a 0. The researchers created two-bit memory cells by giving the glass two more states in between amorphous and crystalline. To write data to a memory cell, an electrode heats it until a crystalline filament forms in the amorphous material. The bigger the filament grows, the more current passes through the memory cell. In the amorphous state, the memory cell represents two 0s. In the semiamorphous state, it represents a 0 and a 1. In the semicrystalline state, it represents a 1 and a 0. In the crystalline state, with memory cell resistance at its lowest point, it represents two 1s.

Next steps: The phase-change chips were made using existing fabrication processes that yield memory cells larger than those of a flash memory chip. Future versions of phase-change memory should use newer processes that produce smaller cells, but researchers need to make sure that the technique holds up as the cell sizes shrink.

NANOTECHNOLOGY

Molecular Nanovalves

TINY VALVES CAN RELEASE DRUGS FROM NANO CONTAINERS FOR TARGETED TREATMENTS

SOURCE: "PH-RESPONSIVE SUPRAMOLECULAR NANOVALVES BASED ON CUCURBIT[6]URIL PSEUDOROTAXANES"
Sarah Angelos et al.
Angewandte Chemie 47: 2222–2226

Results: Researchers at the University of California, Los Angeles, have used a complex of molecules to create nanoscale valves for porous silica nanoparticles. The researchers demonstrated that the molecules can seal a fluorescent dye inside the nanoparticles. When the pH of water surrounding a particle changes, part of the nanovalve detaches, allowing the dye to escape.

Why it matters: The nanoparticles could eventually be used to deliver drugs to diseased cells within the body, which differ in pH from healthy cells. A diseased cell that ingested a nanoparticle would cause it to release a drug. Such targeted drug delivery could decrease the side effects of existing treatments and allow the use of drugs that would be either ineffective or lethal if delivered throughout the body. Other nanovalves have been made in the past, but they were activated by special solvents and thus wouldn't work in the body.

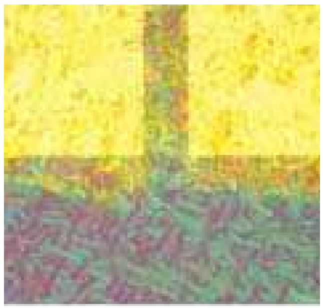
Methods: The researchers made porous silica nanoparticles and chemically treated them, attaching linker molecules to them. After loading the nanoparticles with a fluorescent dye, they sealed the pores by binding molecular complexes to the linkers. Then they placed the nanoparticles in water, raised the pH by adding sodium hydroxide, and monitored the release of the dye.

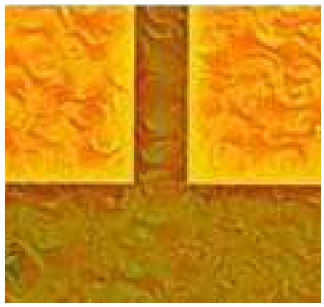
Next steps: The current system works only at harsh pH levels. The researchers are working to develop a system that responds to the gentler pH levels of diseased cells within the body, a crucial modification if the system is to be used for actual drug delivery.

Self-Assembling Transistors

ORGANIC MATERIALS CRYSTALLIZE ON A FLEXIBLE CHIP FOR HIGH-PERFORMANCE ELECTRONICS

SOURCE: "CONTACT-INDUCED CRYSTALLINITY FOR HIGH-PERFORMANCE SOLUBLE ACENE-BASED TRANSISTORS AND CIRCUITS"
David Gundlach et al.
Nature Materials 7: 216–221





An organic semiconductor crystallizes between metal contacts (left). Without a pretreatment, the material does not crystallize (above).

DAVID GUNDLACH/NIST

Results: Researchers at the National Institute of Standards and Technology, Penn State University, and the University of Kentucky have developed a chemical process that helps molecules of an organic semiconductor form transistors on a flexible electronic chip. The molecules crystallize only in the areas between electrical contacts, bridging the gaps between them. In other areas, the organic semiconductor does not crystallize, instead acting as an electrical insulator that prevents unwanted cross talk between transistors.

Why it matters: The process could provide a cheaper way to make high-performance, flexible electronics. Current techniques require either precisely printing semiconductors onto a flexible surface or depositing a semiconductor and etching circuitry into it. Now either step can be skipped. The semiconductor can simply be deposited across the entire surface, and it will self-organize to take on different electronic properties in the appropriate areas.

Methods: The researchers use conventional methods to deposit metallic electrodes on a flexible polyimide substrate. Then they dip the substrate in pentafluorobenzene thiol, which sticks only to the electrodes. Next, they layer the entire surface with an organic semiconductor solution. As the solution dries, it crystallizes on or near the thiol-coated electrodes.

Next steps: The researchers will continue to study the chemistry and kinetics of

the semiconductor to better understand what causes it to crystallize. They are also trying to duplicate the process using other semiconductor materials.

BIOTECHNOLOGY

A Viral Attack on Brain Tumors

RABIES-RELATED VIRUS SEEKS OUT AND DESTROYS CANCER CELLS

SOURCE: "SYSTEMIC VESICULAR STOMATITIS VIRUS SELECTIVELY DESTROYS MULTIFOCAL GLIOMA AND METASTATIC CARCINOMA IN BRAIN"
Anthony N. van den Pol et al.
Journal of Neuroscience 28: 1882–1893

Results: Researchers at Yale University School of Medicine have shown that a specially evolved virus related to the one that causes rabies can rapidly home in on cancer cells. When injected into mice with brain tumors, the virus killed cancerous cells while leaving healthy tissue intact.

Why it matters: Surgery, chemotherapy, and radiation are often insufficient to eradicate brain tumor cells, which can replicate quickly and migrate throughout the brain. A virus that attacks cancer cells while leaving healthy cells unharmed could lead to more effective therapies.

Methods: Scientists had developed the cancer-targeting virus by cultivating it for many generations, each time selecting for strains that quickly infected cancer cells while having little impact on healthy cells. In the new study, researchers used time-lapse laser confocal imaging to watch the virus (tagged fluorescent green) make its way to the brain and attack tumor cells (tagged fluorescent red).

Next steps: Researchers need to observe the virus's behavior in the mice for a longer time to better assess its long-term safety. They also need to determine how well the virus survives in mice with intact immune systems: the animals used in the experiment were immunocompromised to allow cross-species transplantation of human brain cancer cells.

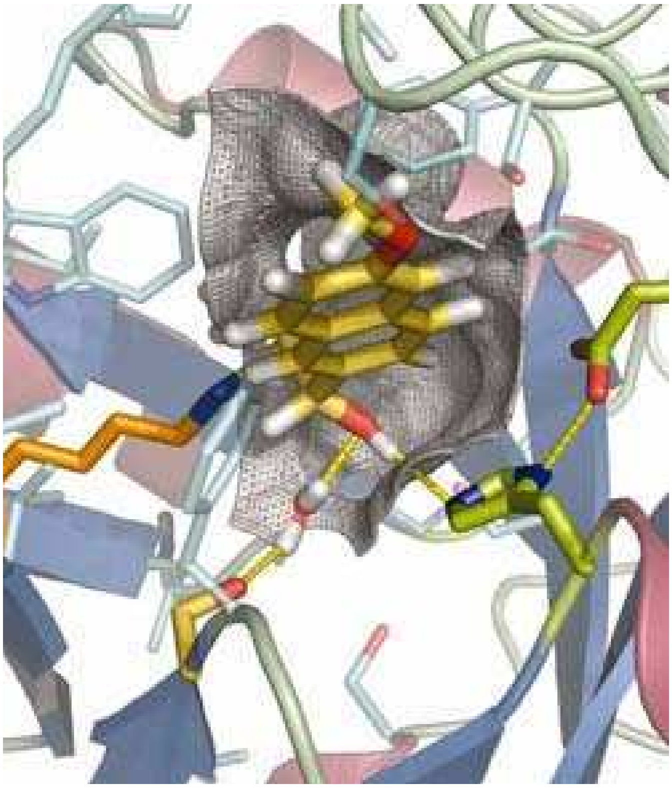
Engineering Enzymes from Scratch

RESEARCHERS DESIGN CATALYSTS USING A NOVEL COMPUTATIONAL TECHNIQUE

SOURCE: "DE NOVO COMPUTATIONAL DESIGN OF RETRO-ALDOL ENZYMES"
David Baker et al.
Science 319: 1387–1391

Results: Scientists from the University of Washington designed enzymes that cause a synthetic chemical to break down 10,000 times as quickly as it would on its own; then they built the enzymes from scratch. No natural enzymes perform the same task.

Why it matters: Novel enzymes that catalyze chemical reactions not normally seen in nature could lead to new ways to make drugs and biofuels and to clean up environmental toxins. Because enzymes are so structurally complex, however, designing new ones has proved extremely difficult.



Part of a model of a newly designed enzyme is shown here. The gray mesh represents a structural element that's crucial to the enzyme's catalytic properties.

Methods: In a biochemical reaction, an enzyme acts on a substrate. Small pockets in the enzyme that bind only to particular substrates give the molecule both its catalytic effect and its specificity. Researchers used a combination of methods, including some that involved quantum chemistry, to design a pocket that they predicted would catalyze the desired reaction. Then they used a series of novel algorithms to model candidate enzymes incorporating the pocket. Finally, the researchers synthesized the proteins and tested their catalytic activity.

Next steps: The researchers want to make the new enzymes as efficient as naturally occurring enzymes, which can increase the rate of a reaction a quadrillion-fold. To do that, they are both improving the algorithms used to generate model proteins and modifying the newly designed enzymes through directed evolution—making a variety of small changes to the enzymes and seeing which ones boost efficiency. TR

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"A Who's Who of the Unseen"

PUSHING EXPERIMENTATION IN PARTICLE PHYSICS

By NATE NICKERSON

This summer, under France and a bit of Switzerland, proton collisions of unprecedented force will offer fresh insight into the nature of matter. You'll find photos of the Large Hadron Collider beginning on page 44; on page 10, Jerome Friedman discusses its importance. Friedman won the 1990 Nobel Prize in Physics for particle accelerator experiments confirming the existence of quarks, the elementary particles that make up protons and neutrons. This work was essential to the standard model of particle physics, which Friedman thinks the LHC can help physicists complete. He adds that "if history is a guide, the LHC will also turn up complete surprises, phenomena not anticipated by any theoretical speculation."

History *is* a guide. It's also an echo chamber. In the November 1939 issue of *Technology Review*, MIT physics professor Philip M. Morse argued for more experimentation in particle physics, lest theory go untested. (The polymath Morse went on to organize the Anti-Submarine Warfare Operations Research Group, which helped the U.S. Navy destroy German U-boats; after the war, he turned operations research into a wide field of study.)

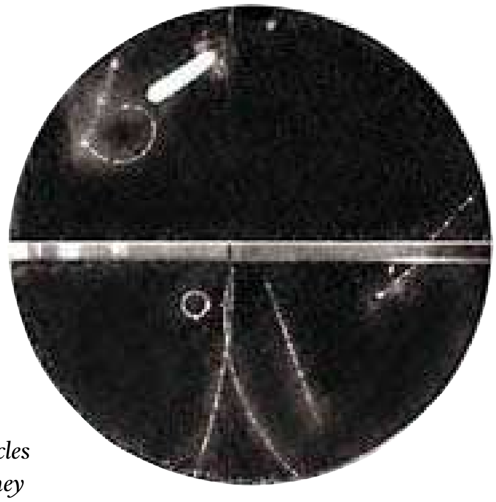
Morse began "Ultimate and Indivisible" with a graceful nod to the distant past:

It seems to have begun with Democritus, this idea of matter's being composed of fundamental, indivisible atoms. Centuries after the time of the great Greek, Dalton used the newly found facts of chemistry to give substance to the speculation. Today we are sure that all matter and all energy are built out of a few kinds of fundamental particles. But we are not sure just how many kinds of particles there are. Nor are we quite sure whether they are really particles and not waves. The investigations by means of which we have reached both our present surety and our present doubts have brought to light particles that would puzzle Democritus, and to language terms that often torment the reader. A survey of this development really resolves itself into a who's who of the unseen.

After reviewing what was known about particles, Morse admonished physicists to put all unproven theories to the test:

Some evidence seems to indicate that when a neutron is transformed into a proton, another particle is given off in addition to the electron. This other particle has been called a neutrino. *The Italian physicist Fermi (another Nobel prize winner, now living in this country) developed a theory of this transformation which predicted the existence of such a particle and indicated that it should have no electric charge but should possess a spin and have a mass much smaller than an electron. Such particles would be quite difficult to detect, and at present only one set of experiments seems to prove their existence.*

Several years ago the Japanese physicist Yukawa studied the theory of the nonelectrical forces between nuclear particles and showed that a corpuscle of radiation might be associated with these forces, just as the photon of light is associated with electrical forces. His studies could not determine whether the predicted particle had spin or electric charge, and his paper ends on an apologetic note after he calculates that the particle should weigh about a hundred times the electron mass, or about $\frac{1}{20}$ *the proton*



Morse's essay included a set of images from a cloud chamber: "The path of an elementary particle," he explained, "is marked by water droplets condensed on the wrecked atoms it leaves behind."

J. C. STREET, E. C. STEVENSON, HARVARD UNIVERSITY

mass. A few recent observations of the constituents of cosmic rays seem to indicate that this intermediate particle actually does exist. It has been called the meson, *or* mesotron.

Thus Democritus' conception of the economy of nature in its use of building materials for the universe seems to be finally demonstrated, although the picture is not so simple as one might hope. Two kinds of particles, protons and neutrons, make up all atomic nuclei; one other kind, the electron, makes up the outer structure and completes the atom as chemists know it. There is the ephemeral positron, closely related to the electron, and there is the photon, which carries electromagnetic energy. There are, in addition, possibly the elusive neutrino and the welterweight meson.

... The amazing feat of [Paul] Dirac in predicting the positron before its discovery, and the possibly successful prophecies of Fermi and Yukawa concerning the neutrino and the meson, constitute a heartening victory for the modern quantum theory. Nevertheless it is dangerous to become overconfident in the infallibility of purely theoretical analysis and so to neglect experimental science. Many other predictions made during the past ten years have been proved wrong. No theory, no matter how beautiful its equations, has any more value than Democritus' original speculation until its predictions have been verified by the hard-boiled experimenters. TR

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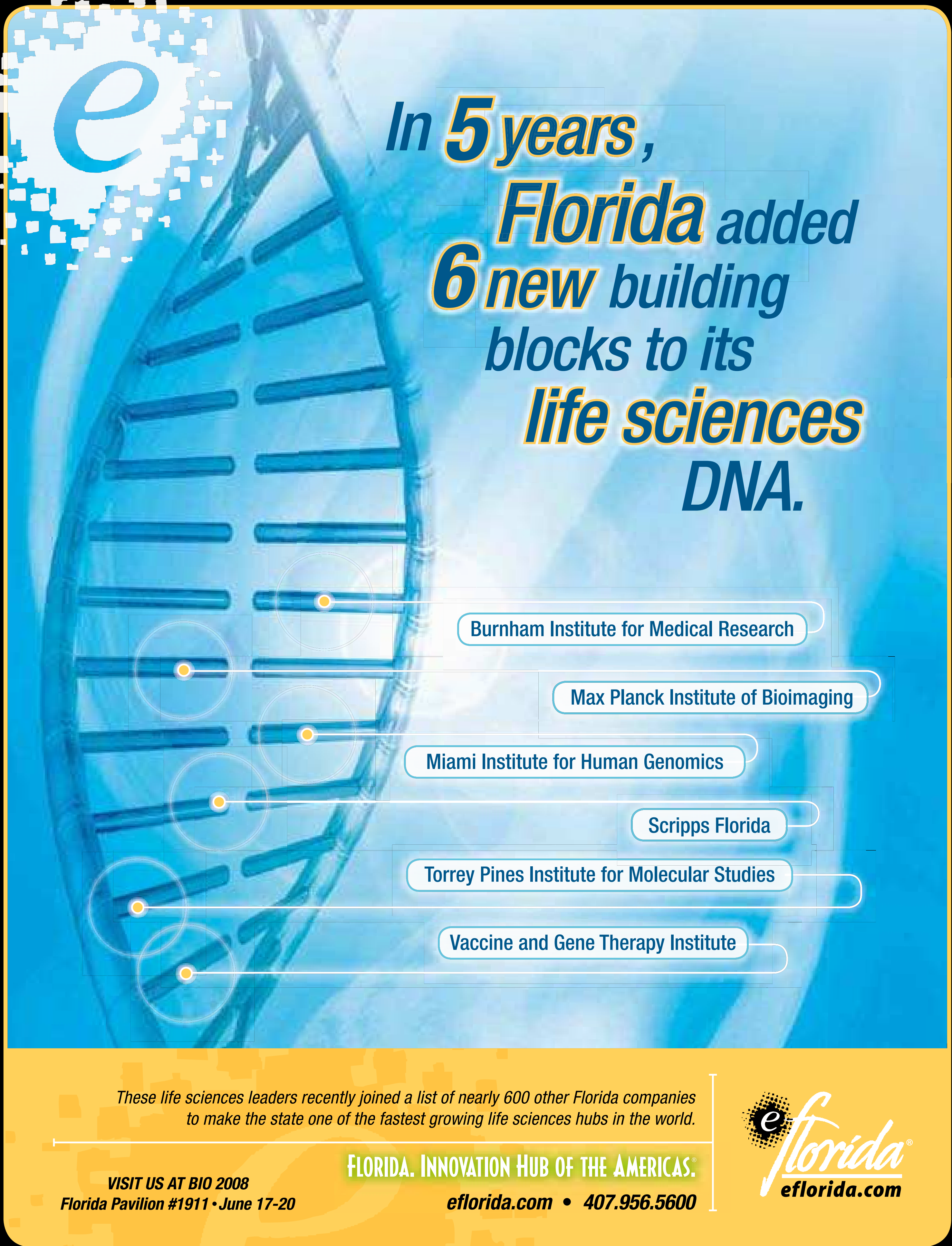

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